# ANALYSIS OF AIR CONDITIONING FOR EXISTING M.I.T. BUILDINGS

by

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Department of Mechanical Engineering

M. S. Thesis August 1968

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## ABSTRACT

The purpose of this study is to investigate the relative installation costs and advantages and disadvantages of three air conditioning systems for building 3 at M.I.T. The three systems examined are: window and package units with a separate outside air supply, fan coil units with a separate outside air supply, and an air induction system.

The fan coil units with separate outside air supply was found to be the overall best system to install in building 3.

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# I. INTRODUCTION

Many times it becomes desirous to add summer cooling to an old existing permanent building, such as located at M.I.T. One of the first questions is that of just what kind of system should be installed, and what would be the relative installation costs of various systems.

This report compares the equipment procurement and installation costs and points out the relative advantages and disadvantages of three basic systems. The three systems examined are:

System 1: Add window or package air conditioning units and a separate outside air supply. Present heating system is kept in place.

System 2: Add chill water fan coil units and a separate outside air supply. Present heating system is kept in place.

System 3: Add four-pipe high pressure induced air units. Present heating system is removed.

These three systems were chosen as representative of the methods that would normally be employed, and there is no implication that these are the only ones that could be used.

The north-south wing of building 3, M.I.T. (that which was originally constructed as building 7) was chosen as a representative building and is used as the basis for this report's results and conclusions. The east-west section of building 3 was not included as it is felt that that portion of building 3 would be more appropriately included in any system encompassing building 7 and 10's east-west section.

Chapter II of this report outlines and discusses building 3's maximum probable cooling demand. Chapters III, IV, and V examine each system

to be considered, and Chapter VI summarizes and presents the report's conclusions.

## II. MAXIMUM PROBABLE COOLING DEMAND

### A. Assumptions

In determining the maximum probable cooling demand, the following assumptions were made:

1. Outdoor design conditions: 95 $^{o}$F dbt; 78 $^{o}$F wbt
2. Inside design conditions: 75 $^{o}$F dbt; 50% relative himidity
3. Before any air conditioning system is installed, the windows are effectively weatherstripped which, along with the slight positive pressure of the ventilation system, results in no air infiltration except through open exterior doors.
4. The main purpose of the air conditioning is for human confort, and there is no process work requiring exact temperature and humidity control.
5. Moisture permeation is negligible, since this is a comfort job with good building construction.
6. Adjacent buildings are air conditioned.
7. Heat loss through basement floors and sidewalls, underground level, is neglected. This heat loss is handled the same as solar heat gain is in determining the maximum probable heating demand. This floor loss will tend to reduce the cooling load, but as no exact amount can be counted on, it is neglected, and any heat loss is just a bonus to the cooling load.
8. In determing the solar heat gain, all windows were assumed to have light color venetian blinds.

### B. Maximum Probable Cooling Demand Tables

Tables 1 through 11 give the maximum probable cooling demand by room for the north-south wing of building 3. Appendix A gives a detail breakdown

of the sensible heat portion of the cooling demand along with a discussion of how the loads were determined.

TABLE 1

Maximum Probable Cooling Demand
First Floor, N. E. Side, Building 3

| Room No. | Grains per Hour | Latent Load $Q_L$ Btuh | Latent per $ft^2$ $Q_L/ft^2$ | Sensible Load Total $Q_s$ Btuh | Sensible per $ft^2$ $Q_s/ft^2$ |
|---|---|---|---|---|---|
| 132 | 1200 | 180 | 0.55 | 10573 | 32 |
| 134 (A) | 2400 | 360 | 1.3 | 12973 | 47 |
| 136 | 2400 | 360 | 1.38 | 12318 | 48 |
| 138 | 1200 | 180 | 0.56 | 13509 | 42 |
| 140 | 2400 | 360 | 1.33 | 12363 | 46 |
| 142 | 1200 | 180 | 0.67 | 14713 | 55 |
| 144 | 2400 | 360 | 1.3 | 14933 | 54 |
| 146 | 1200 | 180 | 0.56 | 14950 | 46 |
| 148 | 7200 | 1080 | 5.9 | 15015 | 83 |
| 152 | 7200 | 1080 | 5.9 | 15015 | 83 |
| 154 | 1200 | 180 | 0.53 | 13043 | 38 |
| 156 | 2400 | 360 | 1.43 | 12908 | 51 |
| 158 | 1200 | 180 | 0.77 | 12103 | 52 |
| 160 | 1200 | 180 | 0.77 | 12103 | 52 |
| 162 | 1200 | 180 | 0.77 | 12103 | 52 |
| 164 (A) | 2400 | 360 | 1.25 | 12323 | 43 |
| 166 | 1200 | 180 | 0.63 | 12103 | 42 |
| 174 | 3600 | 540 | 0.92 | 19739 | 34 |
| Totals | 43,200 | 6480 | | 242,787 | |

TABLE 2

Maximum Probable Cooling Demand

First Floor, S. W. Side, Building 3

| Room No. | Grains per Hour | Latent Load $Q_L$ Btuh | Latent per $ft^2$ $Q_L/ft^2$ | Sensible Load Total $Q_s$ Btuh | Sensible per $ft^2$ $Q_s/ft^2$ |
|---|---|---|---|---|---|
| 131 | 5000 | 750 | 2.4 | 10510 | 34 |
| 133 | 122,000 | 18,300 | 19.6 | 45873 | 49 |
| Projection Booth | | | | | |
| 133 | 2400 | 360 | 7.6 | 4500 | 98 |
| 137 | 2400 | 360 | 0.64 | 2940 | 5 |
| 137 (A) | 1200 | 180 | 0.72 | 14952 | 59 |
| 137 (B) | 1200 | 180 | 1.25 | 7808 | 54 |
| 137 (C) | 1200 | 180 | 1.25 | 7808 | 54 |
| 137 (D) | 1200 | 180 | 0.8 | 15066 | 67 |
| 143 | 50,000 | 7,500 | 2.2 | 590,010 | 175 |
| 157 | 20,000 | 3,000 | 1.5 | 167,040 | 82 |
| 167 | 2000 | 300 | 2.7 | 1000 | 9 |
| 169 | 2000 | 300 | 0.5 | 290,000 | 484 |
| 173 | 4800 | 720 | 2.7 | 2500 | 10 |
| 182 | 2400 | 360 | 1.0 | 10,056 | 27 |
| Totals | 217,800 | 32,670 | | 1,170,063 | |

TABLE 3

Maximum Probable Cooling Demand

Second Floor, N. E. Side, Building 3

| Room No. | Grains per Hour | Latent Load $Q_L$ Btuh | Latent per $ft^2$ $Q_L/ft^2$ | Sensible Load Total $Q_s$ Btuh | Sensible per $ft^2$ $Q_s/ft^2$ |
|---|---|---|---|---|---|
| 232 | 1200 | 180 | 0.5 | 9115 | 26 |
| 234 | 1200 | 180 | 0.7 | 11447 | 42 |
| 236 | 1200 | 180 | 0.7 | 11447 | 42 |
| 238 | 1200 | 180 | 0.6 | 11447 | 39 |
| 240 | 1200 | 180 | 0.7 | 11447 | 41 |
| 242 | 1200 | 180 | 0.7 | 11447 | 41 |
| 244 | 1200 | 180 | 0.7 | 11447 | 41 |
| 246 | 1200 | 180 | 0.6 | 11539 | 39 |
| 248 | 1200 | 180 | 0.7 | 12109 | 49 |
| 250 | 2400 | 360 | 1.5 | 14261 | 58 |
| 252 | 1200 | 180 | 0.7 | 12109 | 49 |
| 254 | 1200 | 180 | 1.5 | 1080 | 9 |
| 254 (A) | 1200 | 180 | 1.1 | 9487 | 56 |
| 256 | 1200 | 180 | 0.6 | 11447 | 39 |
| 258 | 2400 | 360 | 1.2 | 11667 | 40 |
| 260 | 1200 | 180 | 0.6 | 11447 | 39 |
| 262 | 1200 | 180 | 0.6 | 10137 | 34 |
| 264 | 2400 | 360 | 0.6 | 10357 | 35 |
| 266 | 1200 | 180 | 0.6 | 10137 | 34 |
| 270 | 422,620 | 63,500 | 4.5 | 70,890 | 51 |
| Totals | 449,020 | 67,460 | | 274,464 | |

TABLE 4

Maximum Probable Cooling Demand

Second Floor, S. W. Side, Building 3

| Room No. | Grains per Hour | Latent Load $Q_L$ Btuh | Latent per ft$^2$ $Q_L/ft^2$ | Sensible Load Total $Q_s$ Btuh | Sensible per ft$^2$ $Q_s/ft^2$ |
|---|---|---|---|---|---|
| 231 | 8000 | 1200 | 2.4 | 13294 | 26 |
| 235 | 37,200 | 5600 | 3.2 | 68201 | 39 |
| 235 (B) | 4800 | 720 | 4.3 | 2070 | 12 |
| 253 | 50,000 | 7500 | 1.4 | 580,178 | 110 |
| 263 and 259 (D) | 4000 | 600 | 1.56 | 119,000 | 310 |
| 269 | 5000 | 750 | 0.1 | 36,598 | 5 |
| 269 (A) | 6000 | 900 | 4.2 | 14,565 | 68 |
| 282 | 3600 | 540 | 1.5 | 6976 | 20 |
| Totals | 118,600 | 17,810 | | 840,882 | |

TABLE 5

Maximum Probable Cooling Demand

Third Floor, N. E. Side, Building 3

| Room No. | Grains per Hour | Latent Load $Q_L$ Btuh | Latent per $ft^2$ $Q_L/ft^2$ | Sensible Load Total $Q_s$ Btuh | Sensible per $ft^2$ $Q_s/ft^2$ |
|---|---|---|---|---|---|
| 332 | 1200 | 180 | 0.5 | 6622 | 17 |
| 334 | 1200 | 180 | 1.4 | 6257 | 48 |
| 334 (A) | 1200 | 180 | 1.1 | 1080 | 7 |
| 336 | 1200 | 180 | 0.6 | 6928 | 24 |
| 338 | 1200 | 180 | 0.6 | 6928 | 24 |
| 340 | 1200 | 180 | 0.6 | 6928 | 24 |
| 242 | 1200 | 180 | 1.2 | 6278 | 42 |
| 342 (A) | 1200 | 180 | 1.3 | 1080 | 8 |
| 344 | 13,560 | 2030 | 3.3 | 16,248 | 27 |
| 348 | 1200 | 180 | 0.8 | 10,207 | 43 |
| 350 | 1200 | 180 | 0.8 | 11,979 | 50 |
| 352 | 1200 | 180 | 0.8 | 10,207 | 43 |
| 354 | 1200 | 180 | 0.6 | 6928 | 23 |
| 356 | 1200 | 180 | 0.6 | 6928 | 23 |
| 358 | 1200 | 180 | 0.6 | 6928 | 23 |
| 360 | 1200 | 180 | 0.6 | 6928 | 23 |
| 362 | 1200 | 180 | 0.6 | 6928 | 23 |
| 364 | 1200 | 180 | 0.6 | 6928 | 23 |
| 366 and 366 (A) | 2400 | 360 | 8 | 7148 | 23 |
| 370 | 422,620 | 63,500 | 45 | 49,144 | 35 |
| Total | 458,980 | 68,950 | | 188,602 | |

TABLE 6

Maximum Probable Cooling Demand

Third Floor, S. W. Side, Building 3

| Room No. | Grains per Hour | Latent Load $Q_L$ Btuh | Latent per $ft^2$ $Q_L/ft^2$ | Sensible Load Total $Q_s$ Btuh | Sensible per $ft^2$ $Q_s/ft^2$ |
|---|---|---|---|---|---|
| 331 | 5000 | 750 | 1.9 | 7859 | 20 |
| 333 | 12,000 | 1800 | 0.7 | 19,672 | 40 |
| 335 | 12,000 | 1800 | 0.7 | 19,672 | 40 |
| 339 | 8400 | 1260 | 0.3 | 22,062 | 29 |
| 339 (A) | 1200 | 180 | 0.8 | 13,292 | 61 |
| 339 (B) | 1200 | 180 | 1.1 | 12,661 | 79 |
| 339 (D) | 4800 | 720 | 3.1 | 4400 | 19 |
| 343 | 108,000 | 16,200 | 16.3 | 39,985 | 40 |
| 347 | 12,000 | 1800 | 1.9 | 201,390 | 21 |
| 351 | 12,000 | 1800 | 1.9 | 201,390 | 21 |
| 355 | 12,000 | 1800 | 1.9 | 201,390 | 21 |
| 359 | 1200 | 180 | 0.6 | 1735 | 6 |
| 359 (A) | 1200 | 180 | 0.8 | 12,797 | 59 |
| 359 (B) | 2400 | 360 | 1.3 | 12,927 | 46 |
| 359 (C) | 4800 | 720 | 3.6 | 2390 | 12 |
| 363 | 1200 | 180 | 0.9 | 30,000 | 148 |
| 365 | 4000 | 600 | 1.2 | 100,432 | 208 |
| 365 (B) | 2400 | 360 | 1.7 | 13,962 | 65 |
| 369 | 2400 | 360 | 1.4 | 65,000 | 261 |
| 382 | 2400 | 360 | 1.1 | 7881 | 23 |
| Totals | 184,140 | 27,621 | | 990,897 | |

TABLE 7

Maximum Probable Cooling Demand

Fourth Floor, N. E. Side, Building 3

| Room No. | Grains per Hour | Latent Load $Q_L$ Btuh | Latent per $ft^2$ $Q_L/ft^2$ | Sensible Load Total $Q_s$ Btuh | Sensible per $ft^2$ $Q_s/ft^2$ |
|---|---|---|---|---|---|
| 432 | 4500 | 685 | 1.9 | 10,985 | 31 |
| 434 | 67,800 | 10,170 | 10.9 | 116,800 | 125 |
| 438 | 67,800 | 10,170 | 10.9 | 116,800 | 125 |
| 442 | 67,800 | 10,170 | 21.9 | 18,936 | 41 |
| 444 | 67,800 | 10,170 | 21.9 | 18,936 | 41 |
| 446 | 135,600 | 20,300 | 21.9 | 37,900 | 41 |
| 450 | 4520 | 680 | 1.5 | 19,876 | 43 |
| 452 | 54,240 | 8150 | 8.8 | 30,340 | 33 |
| 456 | 54,240 | 8150 | 8.8 | 30,340 | 33 |
| 462 | 54,240 | 8150 | 8.8 | 30,340 | 33 |
| 464 | 54,240 | 8150 | 9.1 | 30,340 | 33 |
| 470 | 24,000 | 3600 | 2.6 | 25,592 | 19 |
| Totals | 635,180 | 98,545 | | 487,185 | |

TABLE 8

Maximum Probable Cooling Demand

Fourth Floor, S. W. Side, Building 3

| Room No. | Grains per Hour | Latent Load $Q_L$ Btuh | Latent per ft$^2$ $Q_L/ft^2$ | Sensible Load Total $Q_s$ Btuh | Sensible per ft$^2$ $Q_s/ft$ |
|---|---|---|---|---|---|
| 431 | 5000 | 750 | 2.6 | 8663 | 30 |
| 433 | 3600 | 540 | 1.1 | 11,243 | 23 |
| 435 | 1200 | 180 | 0.6 | 10,796 | 37 |
| 437 | 1200 | 180 | 0.5 | 11,220 | 30 |
| 439 | 1200 | 180 | 1.2 | 1914 | 12 |
| 439 (A) | 1200 | 180 | 1.1 | 9489 | 56 |
| 441 | 1200 | 180 | 0.4 | 10,954 | 23 |
| 443 | 1200 | 180 | 0.4 | 10,954 | 23 |
| 445 | 1200 | 180 | 1.2 | 1914 | 12 |
| 445 (A) | 1200 | 180 | 1.1 | 9489 | 56 |
| 447 | 1200 | 180 | 0.4 | 10,954 | 23 |
| 449 | 1200 | 180 | 1.2 | 1914 | 12 |
| 449 (A) | 1200 | 180 | 1.1 | 9489 | 56 |
| 451 | 1200 | 180 | 1.2 | 1914 | 12 |
| 451 (A) | 1200 | 180 | 1.1 | 8509 | 50 |
| 453 | 1200 | 180 | 1.2 | 1914 | 12 |
| 453 (A) | 1200 | 180 | 1.1 | 8509 | 50 |
| 455 | 1200 | 180 | 1.2 | 1914 | 12 |
| 455 (A) | 1200 | 180 | 1.1 | 8509 | 50 |
| 457 | 1200 | 180 | 1.2 | 1914 | 12 |
| 457 (A) | 1200 | 180 | 1.1 | 8509 | 50 |
| 459 | 1200 | 180 | 1.2 | 1914 | 12 |
| 459 (A) | 1200 | 180 | 1.1 | 8509 | 50 |
| 461 | 1200 | 180 | 1.2 | 1914 | 12 |
| 461 (A) | 1200 | 180 | 1.1 | 8509 | 50 |
| 463 | 2400 | 360 | 1.4 | 8855 | 35 |
| 465 | 7200 | 1080 | 2.8 | 13,768 | 35 |
| 482 | 1200 | 180 | 0.8 | 5389 | 24 |
| 482 (A) | 2400 | 360 | 1.0 | 12,976 | 36 |
| Totals | 49,400 | 7410 | | 212,519 | |

TABLE 9

Maximum Probable Cooling Demand

Basement, Building 3

| Room No. | Grains per Hour | Latent Load $Q_L$ Btuh | Latent per $ft^2$ $Q_L/ft^2$ | Sensible Load Total $Q_s$ Btuh | Sensible per $ft^2$ $Q_s/ft^2$ |
|---|---|---|---|---|---|
| 050 | 50,000 | 7500 | 0.8 | 600,694 | 61 |
| 037 | 1200 | 180 | 0.9 | 7545 | 36 |
| 055 | 4000 | 600 | 2.0 | 24,466 | 83 |
| 057 | 4000 | 600 | 2.0 | 26,195 | 89 |
| 059 (A) | 4000 | 600 | 2.0 | 23,318 | 79 |
| 059 (B) | 4000 | 600 | 1.3 | 27,705 | 59 |
| 059 (C) | 4000 | 600 | 1.4 | 27,014 | 65 |
| 054 | 20,000 | 3000 | 10.0 | 44,697 | 144 |
| 056 | 20,000 | 3000 | 10.0 | 44,697 | 144 |
| 058 | 20,000 | 3000 | 10.0 | 44,697 | 144 |
| 060 | 20,000 | 3000 | 10.0 | 44,697 | 144 |
| 062 | 20,000 | 3000 | 10.0 | 44,697 | 144 |
| 064 | 20,000 | 3000 | 10.0 | 44,697 | 144 |
| 066 | 5000 | 750 | 2.8 | 14,000 | 53 |
| 068 | 4000 | 600 | 2.7 | 11,400 | 52 |
| 068 (A) | 4000 | 600 | 5.0 | 11,120 | 93 |
| 070 | 28,000 | 4200 | 2.6 | 13,485 | 8 |
| Behind Test Cells | | | | 13,160 | 10 |
| Outside 068 | | | | 3280 | 6 |
| Front Test Cell | | | | 4100 | 4 |
| Inside Door | | 936 | 4.2 | 4177 | 19 |
| Totals | 232,200 | 35,766 | | 1,079,841 | |

TABLE 10

Maximum Probable Cooling Demand

Hallways, Building 3

| Area | Latent Load Total $Q_L$ Btuh | Sensible Load Total $Q_s$ Btuh |
|---|---|---|
| First Floor South Entrance | 936 | 17,210 |
| First Floor Mid-Hall Entrance | 552 | 15,000 |
| Main Hall | | 12,450 |
| Second Floor Hall | | 20,050 |
| Third Floor Hall | | 16,950 |
| Fourth Floor Hall | | 61,340 |
| Totals | 1488 | 143,000 |

TABLE 11

Maximum Probable Cooling Demand

Grand Total, Building 3

| | Latent Load $Q_L$, Btuh | Sensible Load $Q_s$, Btuh | Total Btuh |
|---|---|---|---|
| Grand Totals | 364,200 | 5,630,240 | 5,994,440 |

Total Load = 500 Tons

C. Instantaneous Heat Gain vs. Instantaneous Cooling Load

Because of the thermal storage capacity of interior walls, floors, furniture, fixtures, etc., the air conditioning equipment may not encounter the space heat gain until several hours after the space first encountered this heat gain. In determining the heat transmission through walls and roofs, the equivalent temperature differentials were used. The equivalent temperature differential tables take into account the time lag for heat transmission through the walls and roofs but do not account for the interior thermal storage of the building; therefore, this thermal storage problem arises not only with solar heat gain through fenestration areas and heat gain from people, lights, and equipment, but also from wall and roof transmissions even though equivalent temperature differentials are used. This thermal storage is closely related to the radiative portion of the heat gain, but at this time, no authoritative means is available for reducing the instantaneous heat gain to instantaneous cooling load.

One suggested approximate method of reducing the instantaneous heat gain to instantaneous cooling load, and the method used in this thesis for determining maximum probable cooling demand, is to divide the heat gain into a convective and radiative portion. The convective portion is taken as an instantaneous cooling load. The radiative portion is reduced or averaged over several hours by the thermal storage of the building. Appendix B outlines in more detail the method used in this paper. Reference A contains a more comprehensive discussion of the thermal storage problem.

The peaks in building 3, using the method described above, occur as follows:

| | |
|---|---|
| East side - first, second, third floor . . . . . . | 8:00 A. M. |
| West side - first, second, third floor . . . . . . | 4:00 P. M. |
| East side - fourth floor . . . . . . . . . . . . . | 12:00 Noon |
| West side - fourth floor . . . . . . . . . . . . . | 4:00 A. M. |
| Basement . . . . . . . . . . . . . . . . . . . . . | 3:00 P. M. |

Because of the thermal storage problem, the times listed above are only approximated. The unknown nature of this thermal storage lag could delay the peak times past that indicated, but at the present time, there is no way to exactly determine this lag without using very expensive and time-consuming measuring procedures at each space.

The thermal storage, besides reducing the peak and causing a time lag, will also tend to reduce the sharp differences in the heat gain over time. For example, if one looks into the solar heat gain tables, there will be, in some cases, large differences in the solar heat gain over a one-hour period. The thermal storage will tend to reduce this sharp difference with the result that the cooling load will actually rise slower than would be indicated by the solar heat gain tables and will slowly fall off as the peak is past instead of dropping sharply. In other words, the thermal storage will tend to flatten out the peak, delay it in time, and spread it over a larger time period.

D. Analysis of Sensible Load

An analysis of the sensible load shows the following contributions toward the maximum probable cooling demand:

| Source | Percent of Total Sensible Load |
|---|---|
| Internal Load | 71.3 |
| Glass | 24.0 |
| Walls | 1.8 |
| Skyline | 2.2 |
| Roof | 0.7 |

Two important points are disclosed by the above breakdown. One, the internal load and glass areas, accounts for approximately 95 percent of the total, and two, an even more surprising result, is that the internal load contributes over 71 percent of the total load. This has an important impact in that the load is not as dependent on the time of day as on what's happening internally. With a total load of 500 tons, one would normally expect the sizing of the main refrigeration plant to be approximately 375 tons, as the two sides of the building would not peak simultaneously due to different sun positions. But with this large internal load, the maximum one-time load is 445 tons.

A closer look at the internal load discloses that 88.5 percent of this internal load is from the labs, which are a large source of internal sensible heat. If we substract out this large lab load, the following breakdown results:

| Source | Percent of Total Sensible Load |
|---|---|
| Glass | 65.0 |
| Internal Load | 22.1 |
| Walls | 5.1 |
| Skyline | 6.0 |
| Roof | 1.8 |

This breakdown seems much more reasonable for the normal office-type building with large glass areas. It is noted that the glass areas and internal loads still account for approximately 90 percent of the total load, but the glass areas and internal loads have changed relative positions. The load is now much more dependent on the time of day, and the size of the main refrigeration plant could be reduced.

The above analysis points out the importance of knowing the nature of the cooling load. Two separate buildings may have the same total load, but the nature of this load can have an important impact on the sizing and type of system to be used.

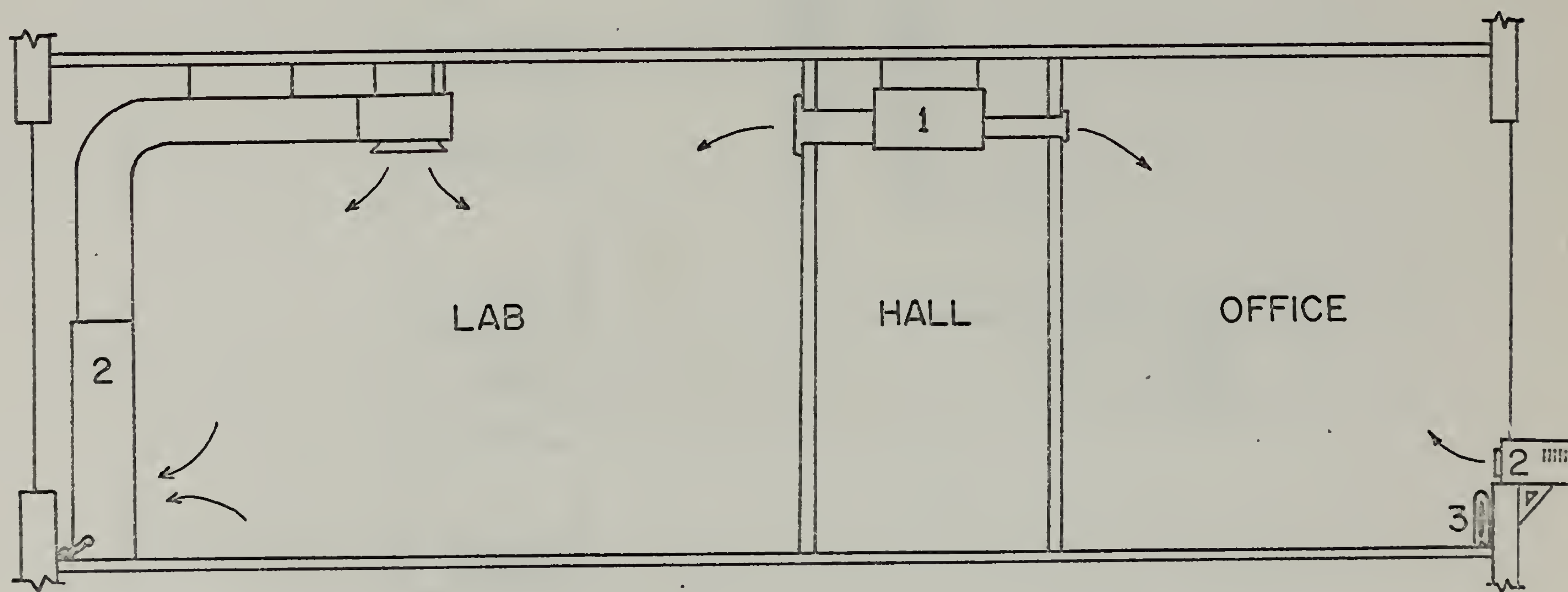
## III. WINDOW UNITS WITH SEPARATE OUTSIDE AIR SUPPLY

### A. System 1 Components

The first system to be analysed as a solution to the air conditioning problem in building 3 is designated System 1. It is composed of a central outside air supply and separate window on package units in each space. Figure 1 shows the main components of this system, and Figure 2 is a partial schematic of the system.

### B. Window and Package Units

Window and package air conditioning units are available in many sizes with various accessories and at different prices, even for the same size units. It is assumed that the best price for the units would be obtained by procuring all units from one manufacturer. This also has the advantage of simplifying and reducing the cost of spare parts support, and simplifying maintenance personnel's job; therefore, one random selected manufacturer's standard unit sizes were used in determining the units required. Another manufacturer may offer a little different sizes, but the overall cost of a complete system with numerous units should be about the same. The unit costs used were the list retail price minus 20 percent. The BTU and wattage ratings used are the manufacturer's stated standard ARI ratings. The units are summer cooling units only and are the manufacturer's standard model. The large package units only are priced with humidity control functions, the purpose of which is explained under Chapter IV-D, Separate Outside Air Supply. Table 12 lists the standard units used.




1. Separate outside air supply
2. Window and package units
3. Present heating system

Figure 1 - System 1, Major Components

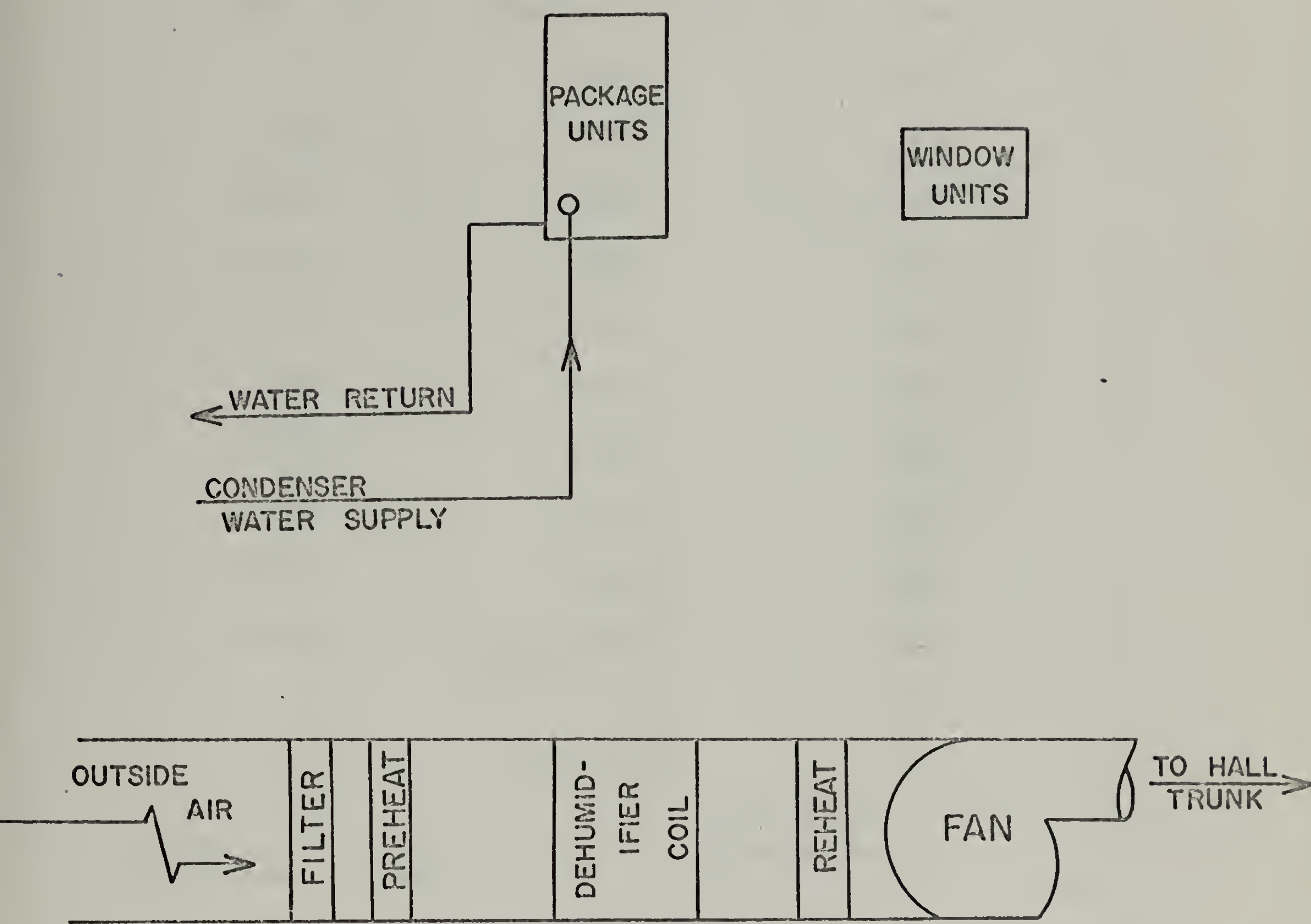



Figure 2 - Partial Schematic, System 1

TABLE 12

Standard Window and Package Units Used

Window Units

| Nominal Size, Btuh | Watts Standard Rating | Cost |
|---|---|---|
| 8000 | 740 | $ 175 |
| 8500 | 1190 | 175 |
| 10,000 | 1960 | 180 |
| 11,000 | 2000 | 180 |
| 14,000 | 2480 | 190 |
| 15,000 | 2500 | 200 |
| 18,700 | 2700 | 230 |
| 23,000 | 3520 | 270 |
| 28,000 | 4110 | 300 |
| 32,000 | 4860 | 350 |

Package Units

| Nominal Size, Tons | Watts Standard Rating | Chill Water Standard Rating GPM | Cost |
|---|---|---|---|
| 3 | 4040 | 4 | $ 1376 |
| 5 | 6140 | 6.6 | 1755 |
| 7-1/2 | 10,200 | 9.3 | 2422 |
| 10 | 14,150 | 13.2 | 3213 |
| 15 | 19,900 | 18 | 4110 |
| 20 | 23,300 | 24 | 5233 |
| 25 | 28,000 | 30 | 6100 |
| 30 | 32,700 | 36 | 6794 |

C. Unit Selection and Cost

Tables13 through 19 list the units used in each space. The general concept used in selection was that window units were selected except where the load was just too much, as in the labs, or where there was no convenient way to vent the condenser heat output to the outside, as in the basement test cells. If one or both of these conditions were present, a water-cooled package unit was selected. The large package units, as utilized in the labs, are capable of having a small duct system installed on their output to provide a more even distribution of the conditioned air over the lab space. These large package units also have humidity control capabilities.

TABLE 13

Window and Package Unit Selections

First Floor, Building 3

| Room No. | No. Units - Size, Btuh | Type Unit | Watts | Cost $ |
|---|---|---|---|---|
| 131 | 1-11,000 | Window | 2000 | 180 |
| 132 | 1-11,000 | " | 2000 | 180 |
| 133 | 2-32,000 | " | 9720 | 700 |
| 134 | 1-14,000 | " | 2480 | 190 |
| 136 | 1-14,000 | " | 2480 | 190 |
| 137 | No Unit | - | - | - |
| 137 (A) | 1-15,000 | Window | 2500 | 200 |
| 137 (B) | 1- 8,000 | " | 740 | 175 |
| 137 (C) | 1- 8,000 | " | 740 | 175 |
| 137 (D) | 1-15,000 | " | 2500 | 200 |
| 138 | 1-14,000 | " | 2480 | 190 |
| 140 | 1-14,000 | " | 2480 | 190 |
| 142 | 1-15,000 | " | 2500 | 200 |
| 143 | 2-30 Ton | Package | 65,000 | 13,588 |
| 144 | 1-15,000 | Window | 2500 | 200 |
| 146 | 1-15,000 | " | 2500 | 200 |
| 148 | 1-18,700 | " | 2700 | 230 |
| 152 | 1-18,700 | " | 2700 | 230 |
| 154 | 1-14,000 | " | 2480 | 190 |
| 156 | 1-14,000 | " | 2480 | 190 |
| 157 | 1-15 Ton | Package | 19,900 | 4110 |
| 158 | 1-14,000 | Window | 2480 | 190 |
| 160 | 1-14,000 | " | 2480 | 190 |
| 162 | 1-14,000 | " | 2480 | 190 |
| 164 | 1-14,000 | " | 2480 | 190 |
| 166 | 1-14,000 | " | 2480 | 190 |
| 167 | No Unit | - | - | - |
| 169 | 1-25 Ton | Package | 28,000 | 6100 |
| 173 | No Unit | - | - | - |
| 174 | 1-23,000 | Window | 3520 | 270 |
| 182 | 1-15,000 | " | 2500 | 200 |
| Totals | | | 179,300 | 29,228 |

TABLE 14

Window and Package Unit Selections

Second Floor, Building 3

| Room No. | No. Units - Size, Btuh | Type Unit | Watts | Cost $ |
|---|---|---|---|---|
| 231 | 1-15,000 | Window | 2500 | 200 |
| 232 | 1-10,000 | " | 1960 | 180 |
| 234 | 1-14,000 | " | 2480 | 190 |
| 235 | 2-32,000<br>1-10,000 | " | 11,680 | 880 |
| 235 (B) | - | - | - | - |
| 236 | 1-14,000 | Window | 2480 | 190 |
| 238 | 1-14,000 | " | 2480 | 190 |
| 240 | 1-14,000 | " | 2480 | 190 |
| 242 | 1-14,000 | " | 2480 | 190 |
| 244 | 1-14,000 | " | 2480 | 190 |
| 246 | 1-14,000 | " | 2480 | 190 |
| 248 | 1-14,000 | " | 2480 | 190 |
| 250 | 1-15,000 | " | 2500 | 200 |
| 252 | 1-14,000 | " | 2480 | 190 |
| 253 | 2-30 Ton | Package | 65,000 | 13,588 |
| 254 | - | - | - | - |
| 254 (A) | 1-14,000 | Window | 2480 | 190 |
| 256 | 1-14,000 | " | 2480 | 190 |
| 258 | 1-14,000 | " | 2480 | 190 |
| 260 | 1-14,000 | " | 2480 | 190 |
| 262 | 1-11,000 | " | 2000 | 180 |
| 263 | 1-10 Ton | Package | 14,150 | 3213 |
| 264 | 1-11,000 | Window | 2000 | 180 |
| 266 | 1-11,000 | " | 2000 | 180 |
| 269 | 1-3 Ton | Package | 4040 | 1376 |
| 269 (A) | 1-15,000 | Window | 2500 | 200 |
| 270 | 1-15 Ton | Package | 19,900 | 4110 |
| 282 | 1- 8500 | Window | 1190 | 175 |
| Totals | | | 165,100 | 27,162 |

TABLE 15

Window and Package Unit Selections

Third Floor, Building 3

| Room No. | No. Units - Size, Btuh | Type Unit | Watts | Cost $ |
|---|---|---|---|---|
| 331 | 1- 8500 | Window | 1190 | 175 |
| 332 | 1- 8000 | " | 740 | 175 |
| 333 | 1-23,000 | " | 3520 | 270 |
| 334 | 1- 8000 | " | 740 | 175 |
| 335 | 1-23,000 | " | 3520 | 270 |
| 336 | 1- 8000 | " | 740 | 175 |
| 338 | 1- 8000 | " | 740 | 175 |
| 339 | 1-23,000 | " | 3520 | 270 |
| 339 (A) | 1-18,700 | " | 2700 | 230 |
| 339 (B) | 1-14,000 | " | 2480 | 190 |
| 339 (D) | No Unit | - | - | - |
| 340 | 1- 8000 | Window | 740 | 175 |
| 342 | 1- 8000 | " | 740 | 175 |
| 342 (A) | No Unit | - | - | - |
| 343 | 2-28,000 | Window | 8220 | 600 |
| 344 | 1-18,700 | " | 2700 | 230 |
| 347 | 1-23,000 | " | 3520 | 270 |
| 348 | 1-11,000 | " | 2000 | 180 |
| 350 | 1-14,000 | " | 2480 | 190 |
| 351 | 1-23,000 | " | 3520 | 270 |
| 352 | 1-11,000 | " | 2000 | 180 |
| 354 | 1- 8000 | " | 740 | 175 |
| 355 | 1-23,000 | " | 3520 | 270 |
| 356 | 1- 8000 | " | 740 | 175 |
| 358 | 1- 8000 | " | 740 | 175 |
| 359 | No Unit | - | - | - |
| 359 (A) | 1-14,000 | Window | 2480 | 190 |
| 359 (B) | 1-15,000 | " | 2500 | 200 |
| 359 (C) | No. Unit | - | - | - |
| 360 | 1- 8000 | Window | 740 | 175 |
| 362 | 1- 8000 | " | 740 | 175 |
| 363 | 1-3 Ton | Package | 4040 | 1376 |
| 364 | 1- 8000 | Window | 740 | 175 |
| 365 | 1-10 Ton | Package | 14,150 | 3213 |
| 365 (B) | 1-15,000 | Window | 2500 | 200 |
| 366 | 1- 8000 | Window | 740 | 175 |
| 369 | 1-5 Ton | Package | 6140 | 1755 |
| 370 | 1-10 Ton | " | 14,150 | 3213 |
| 382 | 1-8500 | Window | 1190 | 175 |
| Totals | | | 102,140 | 16,192 |

TABLE 16

Window and Package Unit Selections

Fourth Floor, Building 3

| Room No. | No. Units - Size, Btuh | Type Unit | Watts | Cost $ |
|---|---|---|---|---|
| 431 | 1-10,000 | Window | 1960 | 180 |
| 433 | 1-14,000 | " | 2480 | 190 |
| 434 | 1-10 Ton | Package | 14,150 | 3213 |
| 435 | 1-11,000 | Window | 2000 | 180 |
| 437 | 1-14,000 | " | 2480 | 190 |
| 438 | 1-10 Ton | Package | 14,150 | 3213 |
| 439 (A) | 1-14,000 | Window | 2480 | 190 |
| 441 | 1-11,000 | " | 2000 | 180 |
| 442 | 1-3 Ton | Package | 4040 | 1376 |
| 443 | 1-11,000 | Window | 2000 | 180 |
| 444 | 1-3 Ton | Package | 4040 | 1376 |
| 445 (A) | 1-14,000 | Window | 2480 | 190 |
| 446 | 1-5 Ton | Package | 6140 | 1755 |
| 447 | 1-11,000 | Window | 2000 | 180 |
| 449 (A) | 1-14,000 | " | 2480 | 190 |
| 450 | 1-3 Ton | Package | 4040 | 1376 |
| 451 (A) | 1-10,000 | Window | 1960 | 180 |
| 452 | 1-3 Ton | Package | 4040 | 1376 |
| 453 (A) | 1-10,000 | Window | 1960 | 180 |
| 455 (A) | 1-10,000 | " | 1960 | 180 |
| 456 | 1-3 Ton | Package | 4040 | 1376 |
| 457 (A) | 1-10,000 | Window | 1960 | 180 |
| 459 (A) | 1-10,000 | " | 1960 | 180 |
| 461 (A) | 1-10,000 | " | 1960 | 180 |
| 462 | 1-3 Ton | Package | 4040 | 1376 |
| 463 | 1-10,000 | Window | 1960 | 180 |
| 464 | 1-3 Ton | Package | 4040 | 1376 |
| 465 | 1-15,000 | Window | 2500 | 200 |
| 470 | 1-3 Ton | Package | 4040 | 1376 |
| 482 | 1- 8000 | Window | 740 | 175 |
| 482 (A) | 1-14,000 | " | 2480 | 190 |
| Totals | | | 109,040 | 22,874 |

TABLE 17

Window and Package Unit Selections

Basement, Building 3

| Room No. | No. Units - Size, Btuh | Type Unit | Watts | Cost $ |
|---|---|---|---|---|
| 050 | 2-30 Ton | Package | 65,000 | 13,588 |
| 037 | 1- 8000 | Window | 740 | 175 |
| 055 | 1-28,000 | " | 4110 | 300 |
| 057 | 1-28,000 | " | 4110 | 300 |
| 059 (A) | 1-28,000 | " | 4110 | 300 |
| 059 (B) | 1-28,000 | " | 4110 | 300 |
| 059 (C) | 1-28,000 | " | 4110 | 300 |
| 054 | 1-5 Ton | Package | 6140 | 1755 |
| 056 | 1-5 Ton | " | 6140 | 1755 |
| 058 | 1-5 Ton | " | 6140 | 1755 |
| 060 | 1-5 Ton | " | 6140 | 1755 |
| 062 | 1-5 Ton | " | 6140 | 1755 |
| 064 | 1-5 Ton | " | 6140 | 1755 |
| 066 | Use 068 Unit | - | - | - |
| 068 | 1-3 Ton | Package | 4040 | 1376 |
| 068 (A) | Use 068 Unit | - | - | - |
| 070 | 1-18,700 | Window | 2700 | 230 |
| Totals | | | 129,870 | 27,399 |

TABLE 18

Window and Package Unit Selections
Hallways, Building 3

| Area | No. Units - Size, Btuh | Type Unit | Watts | Cost $ |
|---|---|---|---|---|
| First Floor Mid-hall Entrance | 1-18,700 | Window | 2700 | 230 |
| First Floor South Entrance | 1-18,700 | Window | 2700 | 230 |
| Fourth Floor Hall | 2-3 Ton | Package | 8080 | 2752 |
| Totals | | | 13,480 | 3212 |

Note: Hallways on first, second, and third floors have no separate units.

TABLE 19

Window and Package Unit Selection
Grand Total

| | Watts | Cost |
|---|---|---|
| Grand Total | 533,830 | 126,068 |

D. Outside Air Supply

Table 20 gives the recommended fresh air supplied to each space. The system supplies 100 percent outside air, which is centrally filtered, preheated, and humidified in winter and cooled and dehumidified in the summer, to meet the outside air volume requirements. The amounts in Table 20 were arrived at by using the following requirements for outside air:

Classroom and Labs . . . . . . . . . . . . 50 cfm per person

Offices . . . . . . . . . . . . . . . . . . 30 cfm per person

Halls . . . . . . . . . . . . . . . . . . . 0.25 cfm per $ft^2$

The above requirements are actually higher than the prescribed minimum but were used to overcome smoking which would be present in almost all spaces and can actually get fairly heavy at times, like in a classroom during final exams. In addition, if the above amounts did not provide for at least one air change per hour, the flow rate was increased to this minimum.

There is no return air system provided, as the air system is provided to meet the outside air requirements. Exhaust air would be removed by undercutting the doors, as the flow rate is very small, or in spaces with large flow rates by providing grills in the doors. The exhaust air would be removed from the halls by exhaust vents to the outside.

The air would be supplied to the spaces at 70 $^oF$ dbt and 60 $^oF$ wbt. This will handle the latent load in the office spaces, providing the design condition of 50 percent rh at maximum probable cooling demand.

This outside air would not handle the latent load and provide for the proper relative humidity in the labs or in the classrooms if the moisture gain exceeded approximately 1300 grains per hour per student, which is quite possible and even expected during times of student tension, as during exams.

Three alternatives were considered for handling the possibly large range of moisture gains in the labs and classrooms. First, one could provide no humidity control other than the constant flow rate of outside air and let the humidity fall where it will. Second, one could provide zoning of the air supply system and meet the latent load in the labs and classrooms with the air supply. Finally, the outside air supply could be designed to meet only the outside air requirements for the labs and classrooms and provide humidity control function on the package units located in these spaces.

The first alternative was rejected as the period when the outside air supply did not meet the latent load requirements in the classrooms is only when the students are under tension, as during an exam, and their moisture release increases. But this is the very time that proper conditions should prevail. At the present time, the labs would not be much of a problem. Supplying the conditioned air at the flow rates indicated by Table 20 would provide the labs with a humidity of between 40 percent and 60 percent under normal conditions, and as there is no process work requiring humidity control, it is felt that this would be an acceptable condition. But the labs are subject to vast changes, and it is quite possible that process work requiring humidity control could

be installed at any time. Some project releasing large amounts of moisture into the air could be installed in a lab at any time, resulting in a large increase in the humidity and the lab environment becoming very unsatisfactory; therefore, it is felt that some form of humidity control should be present, maybe not to hold the humidity to any close tolerance, but at least to keep it in an acceptable range, say 40 percent to 60 percent.

The second alternative of having the outside air supply meet the maximum latent load requirements in the labs and classrooms, recalling that this load is met in the office spaces, was also rejected. Meeting the latent load in all spaces with the outside air supply is a commonly used solution but was rejected in this case primarily because of the unstable nature of the internal loads in the labs. If the lab loads were to remain fairly constant over time, this might be a logical solution. But to provide this capability in the outside air supply system would greatly increase the cost of such a system. The lab could then change drastically, say double or triple, and the system would be insufficient, maybe even before installation was completed. To then change the system might require replacing the ducts with larger sizes and increasing the size of the central air handling plant, causing great inconvenience and incurring additional costs.

The third alternative is the one selected in this case. The outside air supply is sized only to provide the necessary outside air. Supplying this at the before-stated conditions will provide for a relative humidity of between 40 percent and 60 percent in the labs during

normal conditions, that is, up to approximately three-fourths peak conditions, and a relative humidity of approximately 50 percent in the classrooms when the moisture gain does not exceed 1300 grains per hour per student. All spaces where the peak load humidity problem arises, the labs and classrooms, will contain air conditioning package units with humidity control functions. This accomplishes two things: It allows the peak latent load condition to be handled while keeping the cost of the air system down, and more important, it provides the maximum flexibility in that if the latent load should change a great degree from design conditions, the individual package unit may be changed with minimum disruption to the system and at a much less cost than changing the duct system.

The moisture gain in the labs could be improved greatly by better control over lab apparatus set up. During this author's study of the moisture gain in the labs, several instances were observed where raw steam was ejected directly into the lab environment or into open drains. This could be eliminated, or at least drastically reduced, by piping this moisture to an outside drain where possible. This piping would be of a nominal cost and would result in a much more pleasant lab environment.

One last point concerning the solution selected. It is not felt that this suggested solution is generally applicable in all cases but was chosen here because of a combination of two existing facts: the distinct possibility of large changes in the design latent heat gains and the existence of separate package units in each space capable of having humidity control functions installed.

In the winter the air would be supplied at 80 $^{o}$F dbt and 63 $^{o}$F wbt.

There are no special requirements for air purity; therefore, only standard commercial air filters would be used in the central air supply equipment.

The duct system would be sufficiently soundproofed.

TABLE 20

Outside Air Supply by Space

| Room No. | $ft^3$/min. | Room No. | $ft^3$/min. | Room No. | $ft^3$/min. |
|---|---|---|---|---|---|
| 050 | 2000 | 137 (D) | 60 | 234 | 60 |
| 037 | 100 | 143 | 2000 | 236 | 60 |
| 055 | 100 | 157 | 100 | 238 | 60 |
| 057 | 100 | 167 | 30 | 240 | 60 |
| 059 (A) | 100 | 169 | 100 | 242 | 60 |
| 059 (B) | 100 | 173 | 120 | 244 | 60 |
| 059 (C) | 100 | 182 | 60 | 246 | 60 |
| 054 | 100 | 132 | 60 | 248 | 60 |
| 056 | 100 | 134 | 60 | 250 | 60 |
| 058 | 100 | 136 | 60 | 252 | 60 |
| 060 | 100 | 138 | 60 | 254 | 30 |
| 062 | 100 | 140 | 60 | 254 (A) | 30 |
| 064 | 100 | 142 | 60 | 256 | 60 |
| 066 | 100 | 144 | 60 | 258 | 60 |
| 068 | 100 | 146 | 60 | 260 | 60 |
| 068 (A) | 100 | 148 | 300 | 262 | 60 |
| 070 | 600 | 152 | 300 | 264 | 60 |
| Behind | | 154 | 60 | 266 | 60 |
| Test Cell | 345 | 156 | 60 | 270 | 9300 |
| Outside | | 158 | 60 | | |
| 068 | 132 | 160 | 60 | | |
| Front | | 162 | 60 | 331 | 600 |
| Test Cell | 255 | 164 | 60 | 333 | 300 |
| Inside | | 166 | 60 | 335 | 300 |
| Exterior | | 174 | 90 | 339 | 210 |
| Door | 60 | | | 339 (A) | 60 |
| | | | | 339 (B) | 60 |
| | | 231 | 120 | 339 (D) | 60 |
| 131 | 600 | 235 | 1000 | 343 | 2700 |
| 133 | 3000 | 235 (B) | 200 | 347 | 500 |

TABLE 20
(Continued)

Outside Air Supply by Space

| Room No. | ft$^3$/min. | Room No. | ft$^3$/min. | Room No. | ft$^3$/min. |
|---|---|---|---|---|---|
| Proj. Booth | | 253 | 3000 | 351 | 500 |
| 133 | 60 | 263 | 100 | 355 | 500 |
| 137 | 60 | 269 | 200 | 359 | 60 |
| 137 (A) | 60 | 269 (A) | 150 | 359 (A) | 60 |
| 137 (B) | 60 | 282 | 90 | 359 (B) | 60 |
| 137 (C) | 60 | 232 | 60 | 359 (C) | 120 |
| 363 | 60 | 445 | 30 | | |
| 365 | 200 | 445 (A) | 30 | | |
| 365 (B) | 60 | 447 | 60 | | |
| 369 | 60 | 449 | 30 | | |
| 382 | 60 | 449 (A) | 30 | | |
| 332 | 60 | 451 | 30 | | |
| 334 | 30 | 451 (A) | 30 | | |
| 334 (A) | 30 | 453 | 30 | | |
| 336 | 60 | 453 (A) | 30 | | |
| 338 | 60 | 455 | 30 | | |
| 340 | 60 | 455 (A) | 30 | | |
| 342 | 30 | 457 | 30 | | |
| 342 (A) | 30 | 457 (A) | 30 | | |
| 344 | 350 | 459 | 30 | | |
| 348 | 60 | 459 (A) | 30 | | |
| 350 | 60 | 461 | 30 | | |
| 352 | 60 | 461 (A) | 30 | | |
| 354 | 60 | 463 | 60 | | |
| 356 | 60 | 465 | 400 | | |
| 358 | 60 | 482 | 60 | | |
| 360 | 60 | 482 (A) | 60 | | |
| 362 | 60 | 432 | - | | |
| 364 | 60 | 434 | 3000 | | |
| 366 | 60 | 438 | 3000 | | |
| 370 | 9300 | 442 | 1500 | | |
| | | 444 | 1350 | | |
| | | 446 | 3000 | | |
| 431 | 600 | 450 | 150 | | |
| 433 | 90 | 452 | 1200 | | |
| 435 | 60 | 456 | 1200 | | |
| 437 | 60 | 462 | 1200 | | |
| 439 | 30 | 464 | 1200 | | |
| 439 (A) | 30 | 470 | 600 | | |
| 441 | 60 | First Floor | | | |
| 443 | 60 | Hall | 1000 | | |

TABLE 20
(Continued)

Outside Air Supply by Space

| Room No. | $ft^3$/min. |
|---|---|
| Second Floor | |
| Hall | 600 |
| Third Floor | |
| Hall | 600 |
| Fourth Floor | |
| Hall | 600 |
| | |
| Total | 66,402 |

E. Cost of Outside Air Supply

To determine the installed cost of the outside air supply system, the author contacted several air conditioning contractors and examined their standard estimating procedures for outside air supply systems. Using these standard costs plus laying out a system for the north end of the second floor of building 3 and expanding this cost on a square-foot basis over the entire building, a total cost for the system was determined. The standard costs utilized were one dollar per pound for installed duct work and one dollar per square foot of floor space for a completely installed system. The estimate for the outside air supply system, complete and installed is:

Outside air supply system installed including ducts, diffusers, chill water and steam coils, necessary piping, flow controls, fan, and humidifiers . . . . $96,000.

In determining the installed cost of an outside air supply system, it must be recognized that any estimate depends on whether one uses a

high- or low-pressure system, aluminum, galvanized or stainless steel ducts, the gage of the duct metal used, and the duct routing. The above price is based on a high-pressure, galvanized steel duct system, utilizing a central trunk down the main hall passages with a branch duct stubbed into each space. The central air handling equipment would be located in the northeast corner of the basement of building 3, room 050. Figures 1 and 2 offer a partial schematic of the system.

Because of the many variables involved, it is not implied that any ventilation system would cost $96,000, but only that a satisfactory system meeting all the requirements of Table 20 can be installed for a minimum cost of $96,000. It is also important to note that this is a "bare" construction cost in that it does not include any engineering fees, contingency, architectural costs, such as false ceilings, painting, etc., or a contractor's overhead and profit. These costs would all be in addition to the $96,000.

F. Electrical Costs

One of the major costs in installing window and package units is in providing 220-volt electrical service to each unit. These costs were arrived at using standard electrical estimating costs from reference B.

| | |
|---|---|
| Conduit, installed (exposed steel). . . . . . . . | $ 11,400 |
| Wire, installed in conduit. . . . . . . . . . . . . | 16,800 |
| Circuit breakers and 220-V outlets (one per unit) | 2,500 |
| Transformer substation (500 KVA). . . . . . . . . . | 6,000 |
| Total | $ 36,700 |

G. Total Cost System 1

The total cost to procure and install the window and package units and the outside air supply system is:

| | |
|---|---|
| Air conditioning units. . . . . . . . . . . . . . . . | $ 126,068 |
| Air conditioning unit installation. . . . . . . . . | 5,000 |
| Providing 220-V service . . . . . . . . . . . . . . | 36,700 |
| Outside air supply system . . . . . . . . . . . . . | 96,000 |
| Total | $ 263,768 |
| Average Costs . . . . . . . . . . . . . $ 527 per ton | |
| $ 2.68 per $ft^2$ floor | |

The unit installation costs were based on $30 to install a window unit and $50 to install a package unit. This cost covers only placing the unit and connecting the condenser water lines and completing the electrical hook up.

The above cost is a "bare" cost and does not include engineering fees, contingency, architectural costs, or the cost of a separate cooling water system for the package units. It was assumed that cooling water and drains are available in the spaces requiring package units, and the cost to connect into these lines is included in the $50 installation cost.

H. Advantages and Disadvantages of System 1

The major advantages of system 1 are:

1. Relatively easy to install.
2. Can be installed floor by floor
3. Flexibility in design.

4. Flexibility in meeting future load changes.
5. Heating system need not be removed.

The major disadvantages of system 1 are:

1. High maintenance costs and numerous maintenance problems associated with maintaining approximately one hundred fifty separate refrigeration systems instead of one central system.
2. Not adaptable for heating purposes in cold climates.
3. Noisy.
4. Poor control for in-between seasons.
5. Poor temperature control.
6. The package units take up a large amount of floor space.

In deciding whether one should install a system of this type, the above-listed advantages and disadvantages must be weighed against each other and against the results desired. It is not felt that this system would be the best one to install in building 3. Its major advantages of easy installation and flexibility to meet future expansion are far outweighed by the high maintenance costs involved and the poor environmental control afforded by this system. For these reasons system 1 was rejected as a solution for building 3.

## IV. TWO-PIPE FAN COIL UNITS WITH SEPARATE OUTSIDE AIR SUPPLY

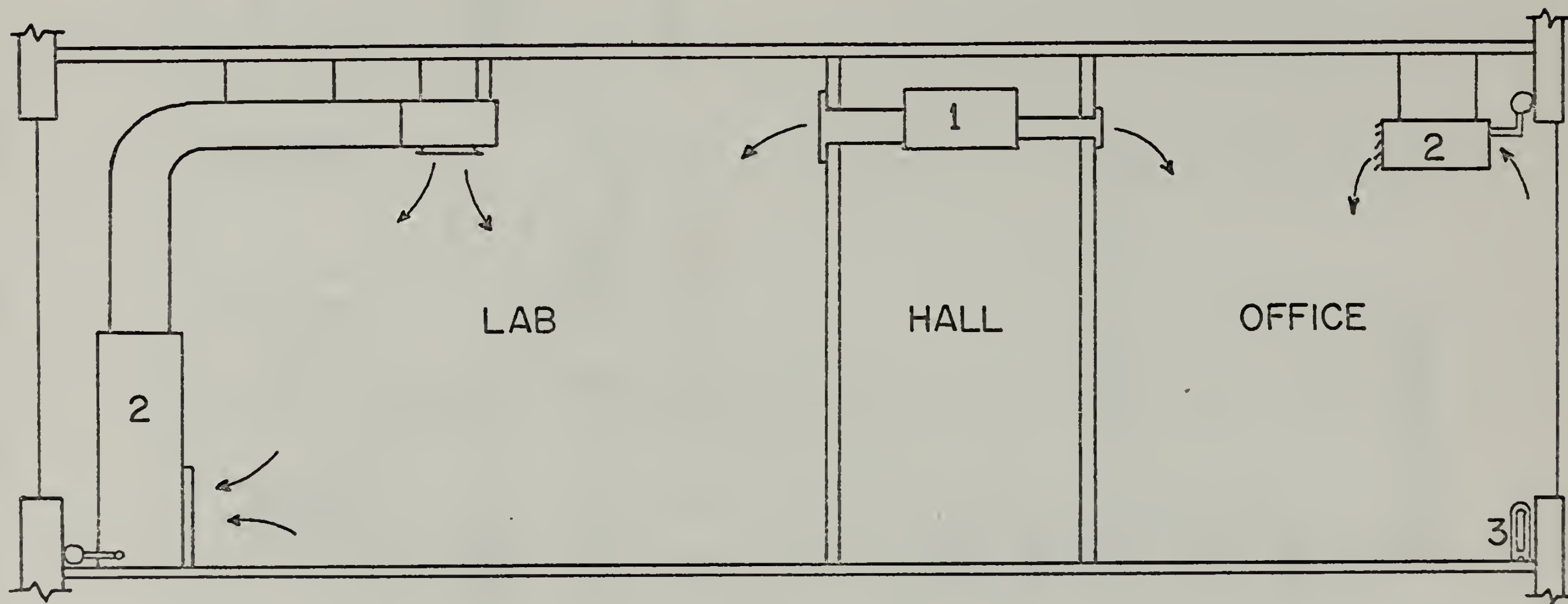
### A. System 2 Components

System 2 is composed of a central outside air supply and individual two-pipe fan coil units for each space. Figure 3 shows the major components of system 2, and Figure 4 is a partial schematic of the system.

### B. Fan Coil Units

Fan coil units offer some of the most flexible units available from a design standpoint. Each normally comes in three or four cabinet arrangements from vertical flow models, to recessed models, to horizontal ceiling-hung models. The larger models, over two or three tons, can be procured with numerous combinations of different fans and coils. They can be obtained with air intake in the front or back, with outlet grills, or with outlet openings fitted onto a duct system. They may have only chill water coils or hot water coils or both on a combination coil. They may be made up for summer cooling only, for year-round cooling and heating, and may contain humidity control capability.

The units selected for this analysis are all ceiling hung, except for the large lab units, two-pipe units designed to provide for summer cooling only. These units were selected mainly to give a system comparable with system 1 so that a cost comparison between the two would be more meaningful. If one wished to provide a year-round fan coil system, this could be done by selecting the proper units and providing the necessary additional hot water piping and controls. A four-pipe fan coil system will be briefly discussed in a later section.




1. Separate outside air supply
2. Fan coil units
3. Present heating system

Figure 3 - System 2, Major Components

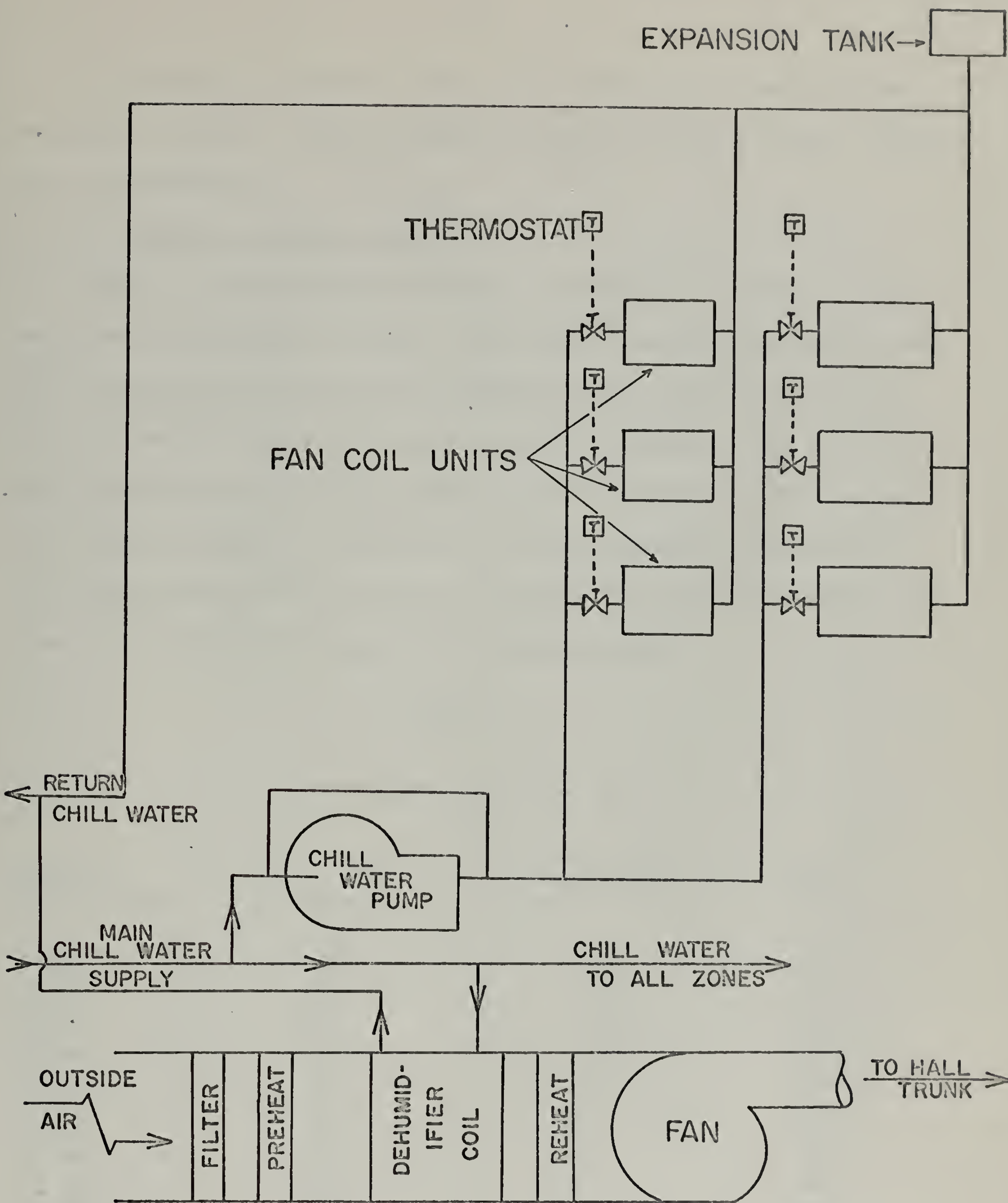



Figure 4 - Partial Schematic, System 2

In selecting the fan coil units, one manufacturer's standard size units were selected. Table 21 gives the units utilized and their operating characteristics.

C. Fan Coil Unit Selection and Cost

Tables 22 through 28 list the units utilized in each space. All units are ceiling-hung, two-pipe, chill water units with temperature control only, except for the lab and classroom units. The classroom units are floor-mounted units with humidity control functions. The lab units are floor-mounted units with humidity control functions and have a small duct system connected to their outlet to provide better circulation of the conditioned air over the large lab area. The unit costs include the cost of all necessary automatic valves and controls.

TABLE 21

Standard Fan Coil Units Used

| Standard Rating, Btuh | Watts | Chill Water Requirements GPM | Cost $ |
|---|---|---|---|
| 4600 | 73 | 1.6 | 150 |
| 7400 | 114 | 2.36 | 165 |
| 10,000 | 134 | 3.22 | 178 |
| 14,200 | 145 | 4.56 | 201 |
| 18,000 | 156 | 5.83 | 220 |
| 24,000 | 177 | 6.5 | 230 |
| 36,000 | 249 | 13 | 262 |
| 60,000 | 373 | 27 | 350 |
| 84,000 | 746 | 27 | 440 |
| 10 tons | 1079 | 30 | 660 |
| 15 tons | 1500 | 35 | 910 |
| 20 tons | | 40 | 1360 |
| 25 tons | 4476 | 45 | 1570 |
| 30 tons | 6000 | 50 | 1850 |

Note: Btuh and chill water figures are nominal standard rates. Actual rates will vary slightly from these given. Units are individual room units with individual controls.

TABLE 22

Fan Coil Unit Selections

First Floor, Building 3

| Room No. | No. Units - Size, Btuh | Watts | Chill Water Requirements GPM | Cost $ |
|---|---|---|---|---|
| 131 | 1-10,000 | 134 | 3.22 | 178 |
| 132 | 1-10,000 | 134 | 3.22 | 178 |
| 133 | 2-36,000 | 497 | 26 | 524 |
| 134 | 1-14,200 | 145 | 4.56 | 201 |
| 136 | 1-14,200 | 145 | 4.56 | 201 |
| 137 | 1- 4,600 | 73 | 1.6 | 150 |
| 137 (A) | 1-14,200 | 145 | 4.56 | 201 |
| 137 (B) | 1-10,000 | 134 | 3.22 | 178 |
| 137 (C) | 1-10,000 | 134 | 3.22 | 178 |
| 137 (D) | 1-14,200 | 145 | 4.56 | 201 |
| 138 | 1-14,200 | 145 | 4.56 | 201 |
| 140 | 1-14,200 | 145 | 4.56 | 201 |
| 142 | 1-14,200 | 145 | 4.56 | 201 |
| 143 | 2-30 Tons | 12,000 | 100 | 3700 |
| 144 | 1-14,200 | 145 | 4.56 | 201 |
| 146 | 1-14,200 | 145 | 4.56 | 201 |
| 148 | 1-18,000 | 156 | 5.83 | 220 |
| 152 | 1-18,000 | 156 | 5.83 | 220 |
| 156 | 1-14,200 | 145 | 4.56 | 201 |
| 157 | 1-15 Tons | 1,500 | 70 | 1820 |
| 158 | 1-14,200 | 145 | 4.56 | 201 |
| 160 | 1-14,200 | 145 | 4.56 | 201 |
| 162 | 1-14,200 | 145 | 4.56 | 201 |
| 164 | 1-14,200 | 145 | 4.56 | 201 |
| 166 | 1-14,200 | 145 | 4.56 | 201 |
| 167 | No Unit | - | - | - |
| 169 | 1-25 Ton | 4,476 | 45 | 1570 |
| 173 | 1- 4,600 | 73 | 1.6 | 150 |
| 174 | 1-24,000 | 188 | 6.5 | 230 |
| 182 | 1-14200 | 145 | 4.56 | 201 |
| 154 | 1-14,200 | 145 | 4.56 | 201 |
| Totals | | 22,120 | 353 | 12,713 |

TABLE 23

Fan Coil Unit Selections

Second Floor, Building 3

| Room No. | No. Units - Size, Btuh | Watts | Chill Water Requirements GPM | Cost $ |
|---|---|---|---|---|
| 231 | 1-14,200 | 145 | 4.56 | 201 |
| 232 | 1-10,000 | 134 | 3.22 | 178 |
| 234 | 1-14,200 | 145 | 4.56 | 201 |
| 235 | 1-84,000 | 746 | 27 | 440 |
| 235 (B) | 1- 4,600 | 73 | 1.6 | 150 |
| 236 | 1-14,200 | 145 | 4.56 | 201 |
| 238 | 1-14,200 | 145 | 4.56 | 201 |
| 240 | 1-14,200 | 145 | 4.56 | 201 |
| 242 | 1-14,200 | 145 | 4.56 | 201 |
| 244 | 1-14,200 | 145 | 4.56 | 201 |
| 246 | 1-14,200 | 145 | 4.56 | 201 |
| 248 | 1-14,200 | 145 | 4.56 | 201 |
| 250 | 1-14,200 | 145 | 4.56 | 201 |
| 252 | 1-14,200 | 145 | 4.56 | 201 |
| 253 | 1-14,200 | 145 | 4.56 | 201 |
| 254 | No Unit | - | - | - |
| 254 (A) | 1-14,200 | 145 | 4.56 | 201 |
| 256 | 1-14,200 | 145 | 4.56 | 201 |
| 258 | 1-14,200 | 145 | 4.56 | 201 |
| 260 | 1-14,200 | 145 | 4.56 | 201 |
| 262 | 1-14,200 | 145 | 4.56 | 201 |
| 263 | 1-10 Ton | 1079 | 30 | 660 |
| 264 | 1-10,000 | 134 | 3.22 | 178 |
| 266 | 1-10,000 | 134 | 3.22 | 178 |
| 269 | 1-3 Ton | 249 | 13 | 262 |
| 269 (A) | 1-18,000 | 156 | 5.83 | 220 |
| 270 | 1-15 Ton | 1500 | 35 | 910 |
| Totals | | 18,628 | 296 | 10,234 |

TABLE 24

Fan Coil Unit Selections

Third Floor, Building 3

| Room No. | No. Units - Size, Btuh | Watts | Chill Water Requirements GPM | Cost $ |
|---|---|---|---|---|
| 331 | 1-10,000 | 134 | 3.22 | 178 |
| 332 | 1- 7,400 | 114 | 2.36 | 165 |
| 333 | 1-24,000 | 177 | 6.5 | 230 |
| 334 | 1- 7,400 | 114 | 2.36 | 165 |
| 335 | 1-24,000 | 177 | 6.5 | 230 |
| 336 | 1- 7,400 | 114 | 2.36 | 165 |
| 338 | 1- 7,400 | 114 | 2.36 | 165 |
| 339 | 1-24,000 | 177 | 6.5 | 230 |
| 339 (A) | 1-18,000 | 156 | 5.83 | 220 |
| 339 (B) | 1-14,200 | 145 | 4.56 | 201 |
| 339 (D) | 1- 4,600 | 73 | 1.6 | 150 |
| 340 | 1- 7,400 | 114 | 2.36 | 165 |
| 342 | 1- 7,400 | 114 | 2.36 | 165 |
| 343 | 1-60,000 | 373 | 27 | 350 |
| 344 | 1-10,000 | 134 | 3.22 | 178 |
| 347 | 1-24,000 | 177 | 6.5 | 230 |
| 348 | 1-10,000 | 134 | 3.22 | 178 |
| 350 | 1-14,200 | 145 | 4.56 | 201 |
| 351 | 1-24,000 | 177 | 6.5 | 230 |
| 352 | 1-10,000 | 134 | 3.22 | 178 |
| 354 | 1- 7,400 | 114 | 2.36 | 165 |
| 355 | 1-24,000 | 177 | 6.5 | 230 |
| 356 | 1- 7,400 | 114 | 2.36 | 165 |
| 358 | 1- 7,400 | 114 | 2.36 | 165 |
| 359 (A) | 1-14,200 | 145 | 4.56 | 201 |
| 359 (B) | 1-14,200 | 145 | 4.56 | 201 |
| 359 (C) | 1- 4,600 | 73 | 1.6 | 150 |
| 360 | 1- 7,400 | 114 | 2.36 | 165 |
| 362 | 1- 7,400 | 114 | 2.36 | 165 |
| 363 | 1-3 Ton | 249 | 13 | 262 |
| 364 | 1- 7,400 | 114 | 2.36 | 165 |
| 365 | 1-10 Ton | 1079 | 30 | 660 |
| 365 (B) | 1-14,200 | 145 | 4.56 | 201 |
| 366 | 1- 7,400 | 114 | 2.36 | 165 |
| 369 | 1-84,000 | 746 | 27 | 440 |
| 370 | 1-10 Ton | 1079 | 30 | 660 |
| 382 | 1-10,000 | 134 | 3.22 | 178 |
| Totals | | 7767 | 244.6 | 8312 |

TABLE 25

Fan Coil Unit Selections

Fourth Floor, Building 3

| Room No. | No. Units - Size, Btuh | Watts | Chill Water Requirements GPM | Cost $ |
|---|---|---|---|---|
| 431 | 1-10,000 | 134 | 3.22 | 178 |
| 433 | 1-14,200 | 145 | 4.56 | 201 |
| 434 | 1-10 Ton | 1079 | 30 | 660 |
| 435 | 1-10,000 | 134 | 3.22 | 178 |
| 437 | 1-14,200 | 145 | 4.56 | 201 |
| 438 | 1-10 Ton | 1079 | 30 | 660 |
| 439 (A) | 1-14,200 | 145 | 4.56 | 201 |
| 441 | 1-10,000 | 134 | 3.22 | 178 |
| 442 | 1-3 Ton | 249 | 13 | 262 |
| 443 | 1-10,000 | 134 | 3.22 | 178 |
| 444 | 1-3 Ton | 249 | 13 | 262 |
| 445 (A) | 1-14,200 | 145 | 4.56 | 201 |
| 446 | 1-5 Ton | 373 | 27 | 350 |
| 447 | 1-10,000 | 134 | 3.22 | 178 |
| 449 (A) | 1-14,200 | 145 | 4.56 | 201 |
| 450 | 1-3 Ton | 249 | 13 | 262 |
| 452 | 1-3 Ton | 249 | 13 | 262 |
| 453 | 1- 7,400 | 114 | 2.36 | 165 |
| 453 (A) | 1-10,000 | 134 | 3.22 | 178 |
| 455 (A) | 1-10,000 | 134 | 3.22 | 178 |
| 456 | 1-3 Ton | 249 | 13 | 262 |
| 457 (A) | 1-10,000 | 134 | 3.22 | 178 |
| 459 | 1- 7,400 | 114 | 2.36 | 165 |
| 459 (A) | 1-10,000 | 134 | 3.22 | 178 |
| 461 (A) | 1-10,000 | 134 | 3.22 | 178 |
| 462 | 1-3 Ton | 249 | 13 | 262 |
| 463 | 1-10,000 | 134 | 3.22 | 178 |
| 464 | 1-3 Ton | 249 | 13 | 262 |
| 465 | 1-14,200 | 145 | 4.56 | 201 |
| 470 | 1-3 Ton | 249 | 13 | 262 |
| 482 | 1- 7,400 | 114 | 2.36 | 165 |
| 482 (A) | 1-14,200 | 145 | 4.56 | 201 |
| Totals | | 7354 | 265.4 | 7626 |

TABLE 26

Fan Coil Unit Selections

Basement, Building 3

| Room No. | No. Units - Size, Btuh | Watts | Chill Water Requirements GPM | Cost $ |
|---|---|---|---|---|
| 050 | 2-30 Ton | 12,000 | 100 | 3700 |
| 037 | 1- 7,000 | 114 | 2.36 | 165 |
| 055 | 1-24,000 | 177 | 6.5 | 230 |
| 057 | 1-24,000 | 177 | 6.5 | 230 |
| 059 (A) | 1-24,000 | 177 | 6.5 | 230 |
| 059 (B) | 1-24,000 | 177 | 6.5 | 230 |
| 059 (C) | 1-24,000 | 177 | 6.5 | 230 |
| 054 | 1-5 Ton | 373 | 27 | 350 |
| 056 | 1-5 Ton | 373 | 27 | 350 |
| 058 | 1-5 Ton | 373 | 27 | 350 |
| 060 | 1-5 Ton | 373 | 27 | 350 |
| 062 | 1-5 Ton | 373 | 27 | 350 |
| 064 | 1-5 Ton | 373 | 27 | 350 |
| 066 | 1-18,000 | 156 | 5.83 | 220 |
| 068 | 1-14,200 | 145 | 4.56 | 201 |
| 068 (A) | 1-14,200 | 145 | 4.56 | 201 |
| 070 | 1-18,000 | 156 | 5.83 | 220 |
| Behind Test Cells | 1-14,200 | 145 | 4.56 | 201 |
| Outside 068 | 1- 4,600 | 73 | 1.6 | 150 |
| Front Test Cells | 1- 4,600 | 73 | 1.6 | 150 |
| Inside Exterior Door | 1- 4,600 | 73 | 1.6 | 150 |
| Totals | | 16,203 | 327 | 8608 |

TABLE 27

Fan Coil Unit Selections

Hallways, Building 3

| Area | No. Units - Size, Btuh | Watts | Chill Water Requirements GPM | Cost $ |
|---|---|---|---|---|
| First Floor Main Hall | 2- 7,400 | 114 | 2.36 | 165 |
| First Floor South Entrance | 1-18,000 | 156 | 5.83 | 220 |
| First Floor Mid-hall Entrance | 1-18,000 | 156 | 5.83 | 220 |
| Fourth Floor Main Hall | 3-18,000 | 468 | 17.5 | 660 |
| Totals | | 894 | 31.5 | 1275 |

Note: Only first- and fourth-floor halls contain units. First floor because of outside entrances; fourth floor because of high heat gain through hallway skylite.

TABLE 28

Fan Coil Unit Selections

Grand Total

| | Watts | Chill Water Requirements GPM | Cost $ |
|---|---|---|---|
| Grand Total | 72,966 | 1517 | 48,768 |

D. Separate Outside Air Supply

The same outside air supply used with system 1 would be used with system 2. The discussion in paragraphs III-D and III-E are applicable to system 2. The humidity control would be handled in the same manner.

E. Total Cost System 2

The total cost to procure and install system 2 is:

| | |
|---|---|
| Fan coil units. . . . . . . . . . . . . . . . . . . . | $ 48,768 |
| Installation. . . . . . . . . . . . . . . . . . . . . | 11,625 |
| Chill water and hot water piping. . . . . . . . . | 55,000 |
| Separate outside air supply . . . . . . . . . . . | 96,000 |
| Total | $ 211,393 |

Average Costs . . . . . . . . .$ 423 per ton

$ 2.14 per $ft^2$ floor

Installation costs were estimated at $75 per unit. This is the cost incurred in connecting the chill water lines, hooking up the fan electrically, mounting the unit, and hooking up the controls. Piping costs include the costs to install a complete chill water system connected to all units. Hot water is only piped to the lab and classroom units to provide the reheat function only. It is not sufficient to provide winter heating and extends to only approximately 10 percent of the spaces. There is no cost for installing a separate electrical circuit for the units. The units' electrical demands are only for one 110-V fan for each unit. It was assumed that each space contained sufficient electrical power to operate the fan without additional power being brought in. Chilled water and steam were assumed to be available,

and no costs were included for their generation. Pipe installation costs were estimated using reference B and include the cost of a small heat exchanger to produce hot water from steam. The costs quoted are "bare" costs as previously explained.

F. Advantages and Disadvantages of System 2

The advantages of a two-pipe fan coil system with separate outside air supply are:

1. Low first cost assuming chill water available.
2. Design flexibility
3. Flexible from the standpoint of later changes to the system.
4. Heating system does not have to be removed.
5. Individual room temperature control.
6. Can be installed floor by floor
7. Lower maintenance cost than system 1.

The system's disadvantages are:

1. Poor in-between season control.
2. Each unit contains a fan motor.

The disadvantage of poor in-between season control can be partially overcome by installing zone water heaters on the two-pipe system or completely overcome by installing a four-pipe system. The four-pipe system would provide good individual space temperature control year round. The additional major components required to install a four-pipe system instead of the two-pipe would be as follows:

| | |
|---|---|
| Hot water piping. . . . . . . . . . . . . . . . . . | $ 58,000 |
| Additional unit costs . . . . . . . . . . . . . . . | 5,500 |
| Flow control valves and additional controls . . . | 3,750 |
| Heat exchanger and water pump . . . . . . . . . . | 9,875 |
| Total | $ 77,125 |

The complete four-pipe fan coil system would cost:

| | |
|---|---|
| Basic two-pipe system . . . . . . . . . . . . . . . | \$ 201,393 |
| Additional cost for four-pipe . . . . . . . . . . | 77,125 |
| Total | \$ 278,518 |

Average Costs. . . . . . . . \$ 557 per ton

\$ 2.83 per $ft^2$ floor.

This initial installation cost of the four-pipe fan coil system is slightly higher than the window and package unit system. Figure 5 is a partial schematic of the four-pipe system.

The main advantages of the two-pipe fan coil system is its low initial cost and its flexibility in meeting future load changes with a minimum cost and disruption to the system as a whole.

In summary, the two-pipe fan coil system offers the lowest initial cost and flexibility in meeting future loads. Its major disadvantage of poor in-between season control can be overcome by expanding to a four-pipe system, but this increases the initial cost above system 1.

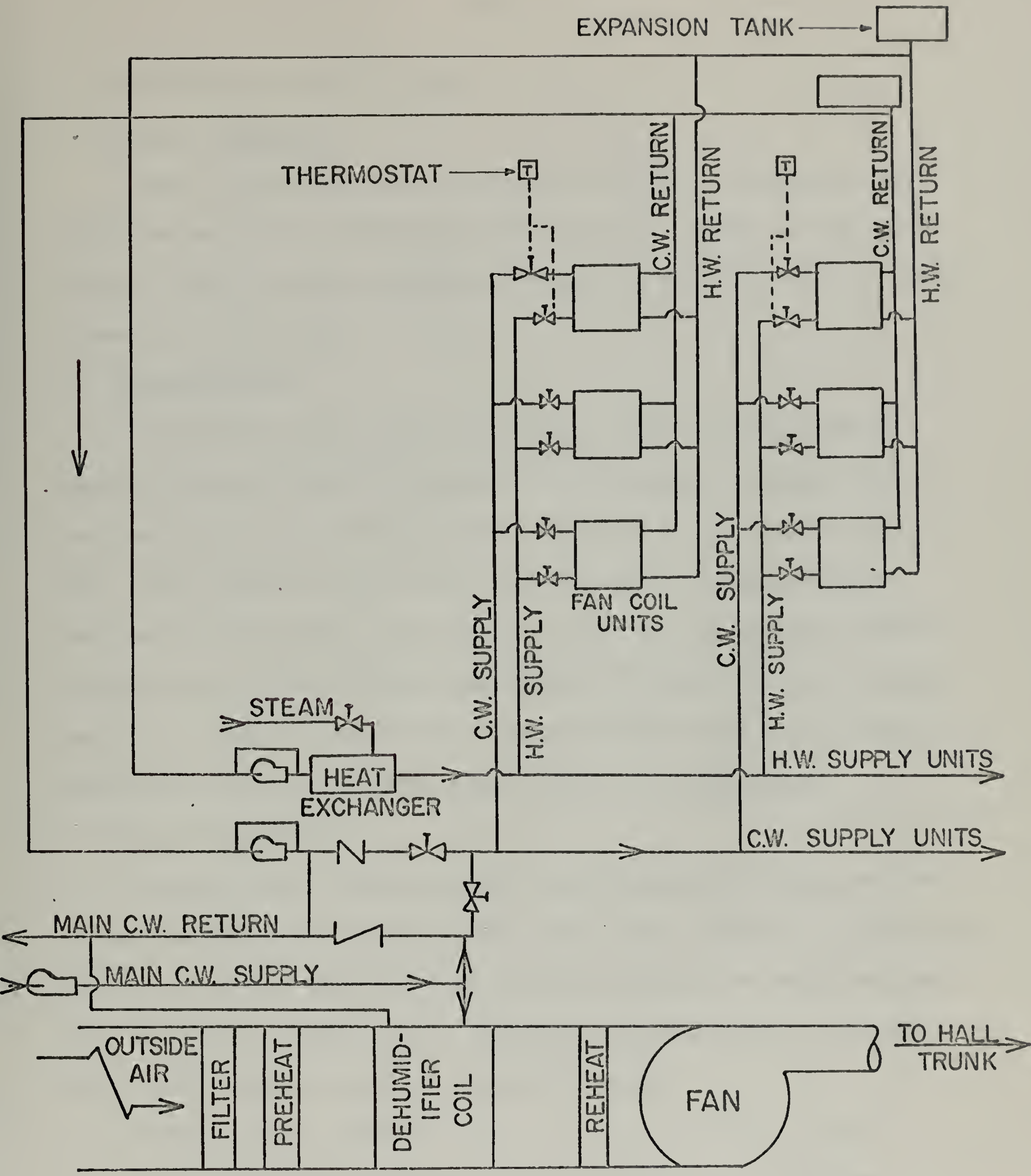



Figure 5 - Partial Schematic, Four-Pipe Fan Coil System

## V. FOUR-PIPE AIR INDUCTION SYSTEM

### A. System 3 Components

System 3 is composed of a central high-pressure, primary air distribution system with individual induction units located in each space. Figure 6 shows the main components of system 3, and Figure 7 is a partial schematic of the system.

### B. Induction Units

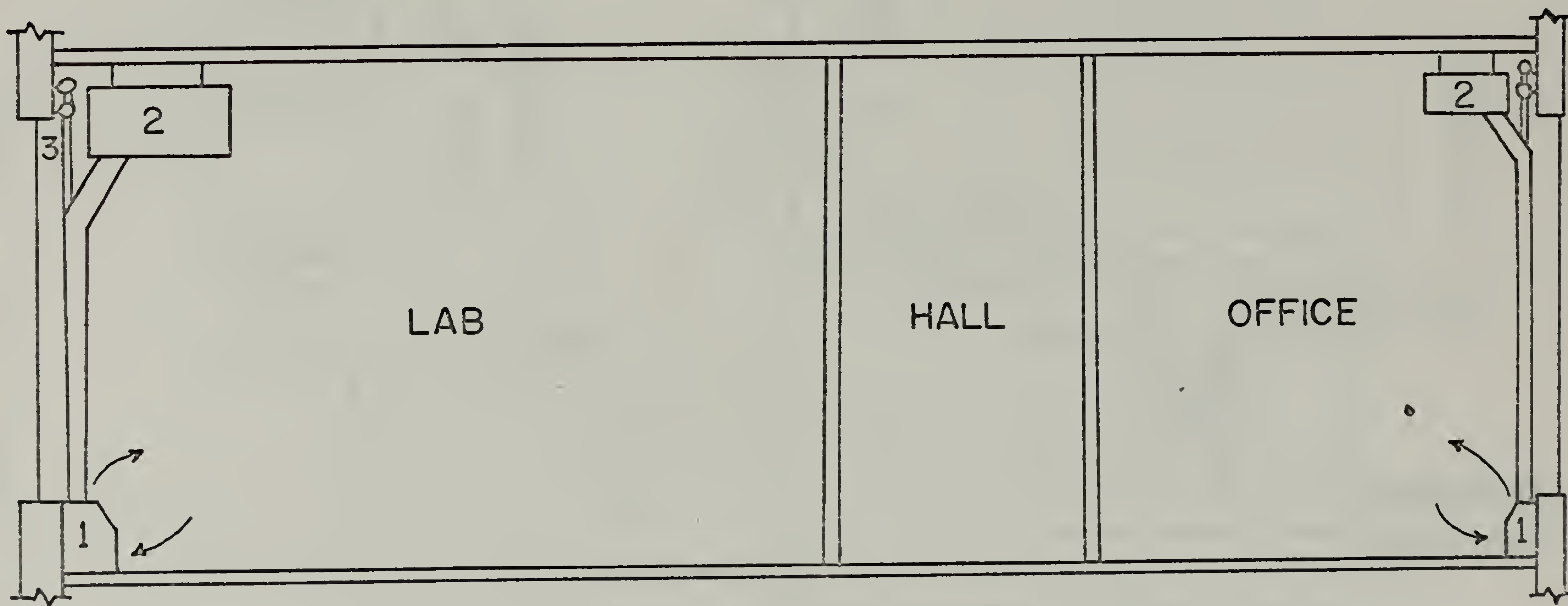
The induction units used are four-pipe units, vertical cabinet models installed below the windows. The primary air distribution system runs around the perimeter of each floor and is hung from the ceiling. Each individual unit's duct extends down the outside vertical wall next to the window. The induction units come in numerous combinations of models with different combinations of nozzle and coil arrangements. At least one manufacturer contacted offered one hundred twenty different variations of model, nozzle, and coil combinations.

### C. Total Cost System 3

The cost of the induction system was determined by laying out the system components for the north end, second floor, building 3, and expanding this cost on a square-foot and per-ton basis for the whole building. This results is a total cost of $373,500. Using reference B standard costs the following total cost breakdown results:

| | |
|---|---|
| Induction units installed. . . . . . . . . . . . . . | $ 66,500 |
| Primary air system including central plant . . . . | 202,000 |
| Chill water and hot water piping system including heat exchanger and pumps . . . . . . . . . | 105,000 |
| Total | $ 373,500 |

Average Costs . . . . . . . . . . . $ 747 per ton
$ 3.79 per ft$^2$ floor




1. Induction units
2. Primary air ducts
3. Cold water and hot water lines

Figure 6 - System 3, Major Components

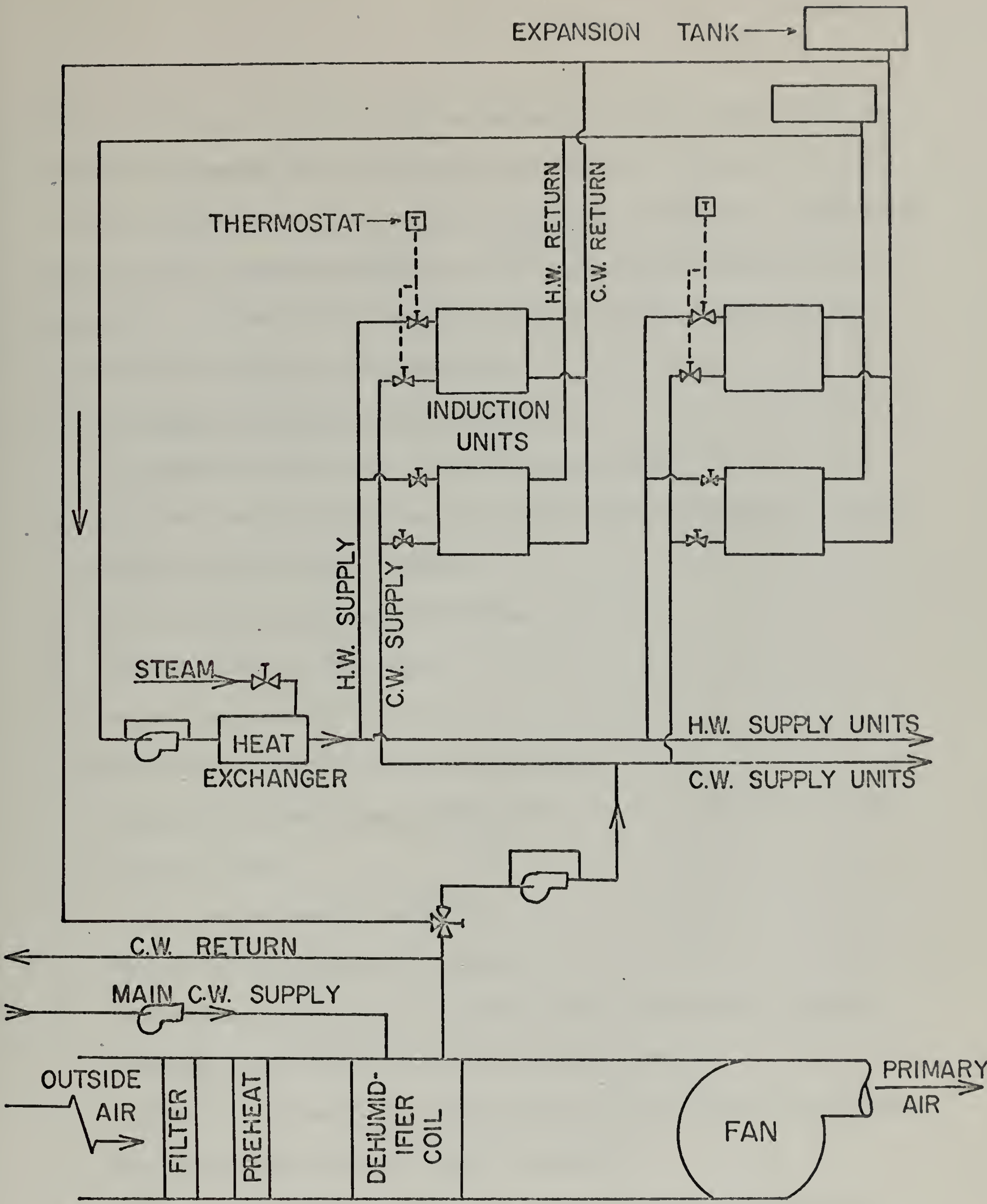



Figure 7 - Partial Schematic, System 3

The above costs, as in all previous cases, are "bare" costs and do not include engineering fees, contingency, contractor overhead, and profit or architectural costs, such as painting, hung ceiling, etc. Chill water and steam were assumed available, and no costs were included for their generation. Primary air is supplied at about 55 $^{o}$F dbt and 54 $^{o}$F wbt to provide for proper space conditions.

D. <u>Advantages and Disadvantages of System 3</u>

The advantages of an air induction system are:

1. Fast and flexible individual room temperature response to room load changes within design conditions.
2. Can be used for heating and cooling.
3. No moving parts in the unit.
4. Low unit maintenance costs.
5. Requires no zoning of air or water system.

The disadvantages of this system are:

1. High first cost.
2. Heating system must be removed.
3. Requires hot water most of the year.
4. Difficult to install and will require more disruption to space occupants during installation than systems 1 and 2.
5. Inflexible to large load changes over and above design conditions.
6. Requires extensive sound control treatment.

The major advantages of the induced air units over systems 1 and 2 are its lack of moving parts in the units and good year-round temperature control. It is noted that the advantage of year-round

temperature control disappears when compared to the four-pipe fan coil system as it offers the same capability.

The induction system's major disadvantages are its high initial cost and inflexibility to design changes. If the load in the labs should change drastically so that the primary air was insufficient, it would require extensive, disruptive, and costly system modifications. Primarily because of these two reasons, initial cost and inflexibility to design changes, this system would not be recommended for building 3. This is not to imply that the induction system is less costly or less desirable than the fan coil system in general, but each application must be individually examined.

The major difference in the cost of the fan coil system and air induction system in this case is the more extensive duct work required for the induction system and the difficulty encountered in installing it in an old building.

# VI. SUMMARY AND CONCLUSIONS

## A. Summary

The relative installation costs and advantages and disadvantages of three separate air conditioning systems for the north-south wing of building 3 at the Massachusetts Institute of Technology have been examined. The two-pipe fan coil system with separate outside air supply (designated system 2) was found to be the cheapest to install at $211,393 or $423 per ton. Window and package units with a separate outside air supply, system 1, was the middle-priced system at $263,768 or $527 per ton, and the high-pressure inducted air system at $373,500 or $747 per ton was found to be the most expensive. The fan coil and induced air systems did not include any chill water or steam generation costs as these were assumed to be available, but the window and package units' costs included, by their nature, the cost of refrigeration production. If chill water and steam were not available, the window and package unit system may well be the cheapest to install.

The window and package units have a serious drawback in their high maintenance costs and numerous maintenance problems associated with maintaining approximately one hundred fifty separate refrigeration units. They also have an objectionable noise, especially for classrooms.

The induction system offers a well-controlled environment, but is considered too expensive to install in building 3 and could pose serious problems if the design loads in the labs were to change.

The fan coil units offer the cheapest solution, specifically for building 3, assuming chill water and steam availability and also offer

maximum flexibility toward future design load changes. If the lab design load should change with the fan coil system, only that particular unit and possibly its chill water supply need be changed. The two-pipe system has some serious drawbacks, such as poor in-between season control, but this can be overcome, and the system can be made to produce high quality year-round environment control, equal to the induced air system by installing a four-pipe fan coil system instead of the two-pipe. This is still cheaper than the induced air system. The four-pipe fan coil system is more expensive to install than the window and package unit system, but should require less total cost over the system's life because of its cheaper maintenance cost. The fan coil units fan does produce some noise, but in the new modern units, this is very low and not considered to be objectionable.

B. Conclusions

From the analysis in this report, it is felt that the best system for building 3 would be the fan coil units with separate outside air supply. If sufficient funds were available, the four-pipe system should be installed, which would produce the best results at the best price. If insufficient funds were available, the two-pipe system should be installed with the possibility of later expanding it to the four-pipe system.

The window and package units and air induction systems certainly have their place and should be looked at whenever considering an application of air conditioning, but are not considered the best solution for building 3.

A close look at the maximum probable cooling demand for building 3 points out the necessity for not only knowing what the total load is, but also what is its character and the behavior of its major components.

# APPENDICES

## APPENDIX A - ROOM PHYSICAL CHARACTERISTICS

Tables 29 and 30 give the physical characteristics of each space in the north-south wing of building 3. These characterisitics are required in determining the heat transmission through walls, volume of outside air required, and size of each space. All physical data were taken from standard drawings furnished by the M.I.T. Physical Plant.

TABLE 29

Room Physical Characteristics

North-South Wing, Building 3

| Room No. | Volume $ft^3$ | Wall $ft^2$ | U | Room No. | Volume $ft^3$ | Wall $ft^2$ | U |
|---|---|---|---|---|---|---|---|
| 131 | 5,020 | 237 | 0.31 | 231 | 7,600 | 232 | 0.31 |
| 132 | 5,300 | 204 | 0.25 | 232 | 5,250 | 204 | 0.25 |
| 133 | 14,000 | 315 | 0.32 | 234 | 4,100 | 143 | 0.34 |
| 133 (A) | 276 | - | - | 235 | 26,300 | 493 | 0.31 |
| 134 | 4,460 | 136 | 0.29 | 235 (B) | 2,540 | - | - |
| 136 | 4,176 | 119 | 0.29 | 236 | 4,100 | 143 | 0.34 |
| 137 | 9,000 | - | - | 238 | 4,100 | 143 | 0.34 |
| 137 (A) | 4,030 | 75 | 0.32 | 240 | 4,100 | 143 | 0.34 |
| 137 (B) | 2,300 | 87 | 0.32 | 242 | 4,100 | 143 | 0.34 |
| 137 (C) | 2,300 | 87 | 0.32 | 244 | 4,100 | 143 | 0.34 |
| 137 (D) | 3,580 | 108 | 0.32 | 246 | 4,450 | 173 | 0.34 |
| 138 | 5,180 | 177 | 0.29 | 248 | 3,720 | 100 | 0.36 |
| 140 | 4,320 | 136 | 0.29 | 250 | 3,720 | 100 | 0.38 |
| 142 | 4,320 | 136 | 0.29 | 252 | 3,720 | 100 | 0.36 |
| 143 | 53,900 | 929 | 0.32 | 253 | 79,000 | 1403 | 0.31 |
| 144 | 4,320 | 136 | 0.29 | 254 | 1,860 | - | - |
| 146 | 5,180 | 227 | 0.29 | 254 (A) | 2,560 | 143 | 0.34 |
| 148 | 2,910 | 76 | 0.27 | 256 | 4,100 | 143 | 0.34 |
| 152 | 2,910 | 76 | 0.27 | 258 | 4,100 | 143 | 0.34 |
| 154 | 5,460 | 243 | 0.29 | 260 | 4,100 | 143 | 0.34 |
| 156 | 4,030 | 111 | 0.29 | 262 | 4,100 | 143 | 0.34 |
| 157 | 32,400 | 710 | 0.32 | 263 | 5,750 | - | - |
| 158 | 3,730 | 136 | 0.29 | 264 | 4,100 | 143 | 0.34 |
| 160 | 3,730 | 136 | 0.29 | 266 | 4,100 | 143 | 0.34 |
| 162 | 3,730 | 136 | 0.29 | 269 | 12,090 | 170 | 0.31 |
| 164 | 3,730 | 136 | 0.29 | 269 (A) | 3,090 | 77 | 0.31 |
| 166 | 4,590 | 136 | 0.29 | 270 | 21,000 | 1098 | 0.21 |
| 167 | 1,810 | - | - | 282 | 5,350 | 239 | 0.31 |
| 169 | 9,600 | - | - | | | | |
| 173 | 4,230 | - | - | | | | |
| 174 | 9,400 | 550 | 0.20 | 331 | 4,900 | 198 | 0.31 |
| 182 | 5,950 | 100 | 0.31 | 332 | 5,000 | 199 | 0.25 |

TABLE 29
(Continued)

Room Physical Characteristics

North-South Wing, Building 3

| Room No. | Volume ft$^3$ | Wall ft$^2$ | U | Room No. | Volume ft$^3$ | Wall ft$^2$ | U |
|---|---|---|---|---|---|---|---|
| 333 | 6,200 | 106 | 0.32 | 382 | 4,250 | 221 | 0.31 |
| 334 | 1,640 | 139 | 0.33 | | | | |
| 334 (A) | 2,040 | - | - | 431 | 3,380 | 166 | 0.31 |
| 335 | 6,200 | 106 | 0.32 | 432 | 4,330 | 228 | 0.28 |
| 336 | 3,680 | 146 | 0.33 | 433 | 5,540 | 118 | 0.31 |
| 338 | 3,680 | 146 | 0.33 | 434 | 10,700 | 357 | 0.28 |
| 339 | 9,650 | 100 | 0.32 | 435 | 3,380 | 101 | 0.31 |
| 339 (A) | 2,720 | 80 | 0.32 | 437 | 4,350 | 147 | 0.31 |
| 339 (B) | 2,000 | 87 | 0.32 | 438 | 10,700 | 357 | 0.28 |
| 339 (D) | 2,900 | - | - | 439 | 1,780 | - | - |
| 340 | 3,680 | 146 | 0.33 | 439 (A) | 1,970 | 118 | 0.31 |
| 342 | 1,880 | 146 | 0.33 | 441 | 5,540 | 118 | 0.31 |
| 342 (A) | 1,800 | - | - | 442 | 5,350 | 178 | 0.28 |
| 343 | 12,400 | 206 | 0.32 | 443 | 5,540 | 118 | 0.31 |
| 344 | 7,600 | 330 | 0.33 | 444 | 5,350 | 178 | 0.28 |
| 347 | 12,000 | 199 | 0.32 | 445 | 1,780 | - | - |
| 348 | 3,000 | 118 | 0.36 | 445 (A) | 1,970 | 118 | 0.31 |
| 350 | 3,000 | 70 | 0.38 | 446 | 10,700 | 357 | 0.28 |
| 351 | 12,000 | 199 | 0.32 | 447 | 5,540 | 118 | 0.31 |
| 352 | 3,000 | 118 | 0.36 | 449 | 1,780 | - | - |
| 354 | 3,680 | 146 | 0.33 | 449 (A) | 1,970 | 118 | 0.31 |
| 355 | 12,000 | 199 | 0.32 | 450 | 5,350 | 178 | 0.28 |
| 356 | 3,680 | 146 | 0.33 | 451 | 1,780 | - | - |
| 358 | 3,680 | 146 | 0.33 | 451 (A) | 1,970 | 118 | 0.31 |
| 359 | 3,610 | - | - | 452 | 10,700 | 357 | 0.28 |
| 359 (A) | 2,710 | 126 | 0.32 | 453 | 1,780 | - | - |
| 359 (B) | 3,480 | 100 | 0.32 | 453 (A) | 1,970 | 118 | 0.31 |
| 359 (C) | 2,520 | - | - | 455 | 1,780 | - | - |
| 360 | 3,680 | 146 | 0.33 | 455 (A) | 1,970 | 118 | 0.31 |
| 362 | 3,680 | 146 | 0.33 | 456 | 10,700 | 357 | 0.28 |
| 363 | 2,540 | - | - | 457 | 1,780 | - | - |
| 364 | 3,680 | 146 | 0.33 | 457 (A) | 1,970 | 118 | 0.31 |
| 365 | 6,010 | 100 | 0.32 | 459 | 1,780 | - | - |
| 365 (B) | 2,700 | 74 | 0.32 | 459 (A) | 1,970 | 118 | 0.31 |
| 366 | 3,680 | 146 | 0.33 | 461 | 1,780 | - | - |
| 369 | 3.110 | - | - | 461 (A) | 1,970 | 118 | 0.31 |
| 370 | 21,000 | 1036 | 0.20 | 462 | 10,700 | 357 | 0.28 |

TABLE 29
(Continued)

Room Physical Characteristics

North-South Wing, Building 3

| Room No. | Volume $ft^3$ | Wall $ft^2$ | U |
|---|---|---|---|
| 463 | 2,900 | 78 | 0.31 |
| 464 | 10,350 | 357 | 0.28 |
| 465 | 4,490 | 328 | 0.31 |
| 470 | 15,700 | 1012 | 0.28 |
| 482 | 2,540 | 155 | 0.28 |
| 482 (A) | 4,190 | 399 | 0.28 |
| 050 | 118,800 | 1984 | * |
| 037 | 2,508 | 99 | 0.33 |
| 055 | 3,534 | 99 | 0.33 |
| 057 | 3,534 | 99 | 0.33 |
| 059 (A) | 3,534 | 130 | 0.30 |
| 059 (B) | 5,472 | 232 | 0.30 |
| 059 (C) | 5,016 | 208 | 0.30 |
| 054 | 3,720 | - | - |
| 056 | 3,720 | - | - |
| 058 | 3,720 | - | - |
| 060 | 3,720 | - | - |
| 062 | 3,720 | - | - |
| 064 | 3,720 | - | - |
| 066 | 3,192 | - | - |
| 068 | 2,500 | - | - |
| 068 (A) | 2,640 | - | - |
| 070 | 12,896 | 144 | 0.31 |

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*S. E. wall U = 0.9
S. W. wall, above high ground U = 0.33
S. W. wall, total wall U = 0.30

TABLE 30

Room Physical Characteristics

Fourth Floor Roof, Building 3

| Room No. | Roof $ft^2$ | Skylight $ft^2$ | Room $ft^2$ | Roof $ft^2$ | Skylight $ft^2$ |
|---|---|---|---|---|---|
| 431 | 390 | - | 462 | 630 | 300 |
| 432 | 176 | 185 | 463 | 246 | - |
| 433 | 318 | - | 464 | 630 | 300 |
| 434 | 630 | 300 | 465 | 410 | - |
| 435 | 287 | - | 470 | 1936 | - |
| 437 | 369 | - | 482 | 202 | - |
| 438 | 630 | 300 | 482 (A) | 364 | - |
| 439 | 155 | - | | | |
| 439 (A) | 163 | - | | | |
| 441 | 318 | - | | | |
| 442 | 315 | 150 | | | |
| 443 | 318 | - | | | |
| 444 | 315 | 150 | | | |
| 445 | 155 | - | | | |
| 445 (A) | 163 | - | | | |
| 446 | 630 | 300 | | | |
| 447 | 318 | - | | | |
| 449 | 155 | - | | | |
| 449 (A) | 163 | - | | | |
| 450 | 315 | 150 | | | |
| 451 | 155 | - | | | |
| 451 (A) | 163 | - | | | |
| 452 | 630 | 300 | | | |
| 453 | 155 | - | | | |
| 453 (A) | 163 | - | | | |
| 455 | 155 | - | | | |
| 455 (A) | 163 | - | | | |
| 456 | 630 | 300 | | | |
| 457 | 155 | - | | | |
| 457 (A) | 163 | - | | | |
| 459 | 155 | - | | | |
| 459 (A) | 163 | - | | | |
| 461 | 155 | - | | | |
| 461 (A) | 163 | - | | | |

Note: U roof = 0.1
U Skylight ceiling = 0.625

## APPENDIX B - MAXIMUM PROBABLE COOLING DEMAND BREAKDOWN

Tables 31 through 35 give a detailed breakdown of the sensible load portion of the maximum probable cooling demand. The following is a short explanation of the method used in arriving at the data in the tables and previous tables which contained the latent load.

1. $Ft^2$ Shaded Glass: The $ft^2$ of shaded glass represents the amount of the window that is in the shade at peak load. It was calculated by determining the size of the shadow cast on the window by any reveal or overhang. The sun's altitude and azimuth at time of peak load was taken from reference A.

2. U Wall: The overall coefficient of heat transfer, the U value, given in the tables is a composite U for the room's exterior wall. It was determined using the equation:

$$U = \frac{U_1A_1 + U_2A_2 + U_3A_3}{A_1 + A_2 + A_3} .$$

3. Btuh Wall: The heat gain through the wall was determined using equivalent temperature differentials, Chapter 28 of reference A. The entries for heavy wall construction were used. To convert this instantaneous heat gain to an instantaneous cooling load, the heat gain was divided into a radiative and convective portion. The convective portion was taken as instantaneous cooling load, and the radiative portion was averaged over a four- to six-hour period up to and including the time of peak load. A detailed example of this method is given in Chapter 28 of reference A. The values given in

this report for the wall heat gain were determined in the same manner as this example in reference A.

4. Shaded Glass, Btuh: The heat gain through the shaded glass is composed of two portions: that gained by transmission (UA$\Delta$t) and that gained by diffuse. The diffuse portion was taken from the solar heat gain tables of reference A. The diffuse heat gain was taken as the solar heat gain on the closest facade to the shaded glass that was in the shade at the time of peak load.

5. Exposed Glass, Btuh: These values were taken from the solar heat gain factors, Chapter 27 of reference A. They were reduced from instantaneous heat gain to instantaneous cooling load using the same method as previously described under the discussion for determining the wall transmission heat gain. The tables for $40^{\circ}$ north latitude were used. The June 21 entries were used for the northeast wall, and the August 21 entries were used for the southwest wall.

6. Internal load, Btuh: The internal load is a summation of all space heat gains from people, lights, motors, and other heat-producing equipment contained in the space. This load was calculated from actual inventory by the author who visited each space. The labs present the biggest variable when determining internal loads. The connected load in the labs is not a reasonable measure as in most labs it is much greater than the power available; therefore, all the connected load could not be operating at once. For this reason the power supply to each lab was used to estimate the internal load

in the labs. To determine if this was reasonable, the M.I.T. Electric Shop was contacted, and they verified that the labs did at times draw the maximum power available. To this electric load was added the sensible load from people, lights, and non-electric heat-producing sources, such as welding, open flames, steam lines, etc. Heat losses from pipes were determined using the equation:

$$q = \frac{t_o - t_a}{\dfrac{r_s \ln \dfrac{r_s}{r_o}}{k_1} + R_s} .$$

This equation and its use are explained in Chapter 26, reference A. Tables 22 and 25, Chapter 26, reference A, were used to determine heat loss from pipe flanges and fittings. One important point to be remembered concerning the internal lab load is that no matter what it is today, it may be vastly different tomorrow.

7. Grains per Hour: The moisture gain was determined by inventorying all the moisture releasing sources in each space. The moisture loss per person used in this report was taken as follows:

| | |
|---|---|
| Seated at rest | 900 gr/hr |
| Seated and working | 1,860 gr/hr |
| Students in classrooms | 2,000 gr/hr |

The moisture loss for the normal office worker was taken as 1,200 grains per hour. This was increased from 900 grains per hour to account for visitors and the times when the office occupant is under tension, as when a professor is involved in solving a difficult problem.

The 2,000 grains per hour for students was used to account for the increased moisture gain of individuals during time of tension, as when taking exams. The labs, again, present a difficult problem in this area. The moisture gain for the labs was arrived at by inventorying all equipment that added moisture to the space and the maximum expected number of students. The moisture gain from lab equipment in some cases was estimated since getting a more accurate measurement would take tremendous time and effort above and beyond the scope of this report. Examples of this are the two steam ejectors in the basement. This author could not detect by inspection or by discussion with lab officials any process that required close humidity control. There is some lab equipment, such as electronic devices, that would benefit from holding the humidity below, say, 60 percent relative humidity, but even these do not require close humidity control. The sensible load to total load ratio in the labs is in the neighborhood of 0.9.

8. Roof, Btuh: The heat gain through the roof was determined in the same manner as previously discussed under Btuh, wall, using the total equivalent temperature differentials for roofs contained in reference A. The table entries for heavy construction roofs exposed to the sun were used.

9. Skylight, Btuh: The heat gain from the roof skylight was determined by estimating the temperature in the skylight during time of peak load for the roof and then calculating the heat transmission into the fourth floor rooms by using the equation $Q = UA\Delta t$.

The temperature in the skylight was estimated by equating Qin to Qout with the skylight temperature as the unknown. Qin was taken as solar heat gain plus internal load such as steam pipes. Qout was taken as the heat transmission (UA$\Delta$t) through the skylight glass and curb and through the fourth floor ceiling under the skylight. This method, though not exact, gives a better estimate of the skylight temperature than guessing. If time were available, actual temperature measurements taken during time of peak load would give a more exact figure. But this should be done over an extended period to ensure good readings, and this would require waiting until the right month, which was not feasible in this case and generally is not feasible in other cases.

TABLE 31

Sensible Heat Load Breakdown

First Floor, Building 3

Southwest Side

| Room No. | Shaded Glass $Ft^2$ | Exposed Glass $Ft^2$ | Wall Btuh | Shaded Glass Btuh | Exposed Glass Btuh | Internal Load Btuh |
|---|---|---|---|---|---|---|
| 131 | 3.5 | 73.5 | 795 | 95 | 8,200 | 1,420 |
| 133 | 11.6 | 234.4 | 1,090 | 313 | 25,600 | 18,870 |
| 133 (A) | - | - | - | - | - | 4,500 |
| 137 | - | - | - | - | - | 2,940 |
| 137 (A) | 5.8 | 117.2 | 260 | 157 | 12,800 | 1,735 |
| 137 (B) | 2.9 | 59 | 302 | 78 | 6,450 | 978 |
| 137 (C) | 2.9 | 59 | 302 | 78 | 6,450 | 978 |
| 137 (D) | 5.8 | 117.2 | 374 | 157 | 12,800 | 1,735 |
| 143 | 40.6 | 820.4 | 3,310 | 1,100 | 89,500 | 496,100 |
| 157 | 27 | 542 | 2,460 | 730 | 59,000 | 104,850 |
| 167 | - | - | - | - | - | 1,000 |
| 169 | - | - | - | - | - | 290,000 |
| 173 | - | - | - | - | - | 2,500 |
| 182 | 3 | 62 | 335 | 81 | 6,580 | 3,060 |
| Totals | | | 9,228 | 2,789 | 227,380 | 930,666 |

Northeast Side

| Room No. | Shaded Glass $Ft^2$ | Exposed Glass $Ft^2$ | Wall Btuh | Shaded Glass Btuh | Exposed Glass Btuh | Internal Load Btuh |
|---|---|---|---|---|---|---|
| 132 | 7 | 86 | 460 | 231 | 7,482 | 2,400 |
| 134 | 8 | 112 | 355 | 264 | 9,744 | 2,610 |
| 136 | 8 | 112 | 310 | 264 | 9,744 | 2,000 |
| 138 | 8 | 112 | 461 | 264 | 9,744 | 3,040 |
| 140 | 8 | 112 | 355 | 264 | 9,744 | 2,000 |
| 142 | 8 | 112 | 355 | 264 | 9,744 | 4,350 |
| 144 | 8 | 112 | 355 | 264 | 9,744 | 4,570 |
| 146 | 8 | 112 | 592 | 264 | 9,744 | 4,350 |
| 148 | 49 | 100 | 198 | 1,617 | 8,700 | 4,500 |
| 152 | 49 | 100 | 198 | 1,617 | 8,700 | 4,500 |
| 154 | 8 | 112 | 635 | 264 | 9,744 | 2,400 |
| 156 | 8 | 112 | 290 | 264 | 9,744 | 2,610 |
| 158 | 8 | 112 | 355 | 264 | 9,744 | 1,740 |
| 160 | 8 | 112 | 355 | 264 | 9,744 | 1,740 |
| 162 | 8 | 112 | 355 | 264 | 9,744 | 1,740 |
| 164 | 8 | 112 | 355 | 264 | 9,744 | 1,960 |
| 166 | 8 | 112 | 355 | 264 | 9,744 | 1,740 |
| 174 | 7 | 143 | 1,190 | 189 | 15,000 | 3,160 |
| Totals | | | 7,529 | 7,350 | 176,498 | 51,410 |

TABLE 32

Sensible Heat Load Breakdown

Second Floor, Building 3

Southwest Side

| Room No. | Shaded Glass $Ft^2$ | Exposed Glass $Ft^2$ | Wall Btuh | Shaded Glass Btuh | Exposed Glass Btuh | Internal Load Btuh |
|---|---|---|---|---|---|---|
| 231 | 4 | 66 | 776 | 108 | 7,200 | 5,210 |
| 235 | 23 | 445 | 1,650 | 621 | 48,500 | 17,430 |
| 235 (B) | - | - | - | - | - | 2,070 |
| 253 | 64 | 1,223 | 4,700 | 1,728 | 134,000 | 439,750 |
| 263 | - | - | - | - | - | 119,000 |
| 269 | 4 | 66 | 570 | 108 | 7,200 | 28,720 |
| 269 (A) | 6 | 111 | 258 | 157 | 12,150 | 2,000 |
| 282 | 3 | 37 | 800 | 81 | 3,920 | 2,175 |
| Totals | | | 8,754 | 2,803 | 212,970 | 616,355 |

Northeast Side

| | | | | | | |
|---|---|---|---|---|---|---|
| 232 | 5 | 70 | | | | |
| 234 | 5.5 | 89.5 | 460 | 165 | 6,090 | 2,400 |
| 236 | 5.5 | 89.5 | 438 | 182 | 7,787 | 3,040 |
| 238 | 5.5 | 89.5 | 438 | 182 | 7,787 | 3,040 |
| 240 | 5.5 | 89.5 | 438 | 182 | 7,787 | 3,040 |
| 242 | 5.5 | 89.5 | 438 | 182 | 7,787 | 3,040 |
| 244 | 5.5 | 89.5 | 438 | 182 | 7,787 | 3,040 |
| 246 | 5.5 | 89.5 | 530 | 182 | 7,787 | 3,040 |
| 248 | 33 | 88 | 324 | 1,089 | 7,656 | 3,040 |
| 250 | 33 | 110 | 342 | 1,089 | 9,570 | 3,260 |
| 252 | 33 | 88 | 324 | 1,089 | 7,656 | 3,040 |
| 254 | - | - | - | - | - | 1,080 |
| 254 (A) | 5.5 | 89.5 | 438 | 182 | 7,787 | 1,080 |
| 256 | 5.5 | 89.5 | 438 | 182 | 7,787 | 3,040 |
| 258 | 5.5 | 89.5 | 438 | 182 | 7,787 | 3,260 |
| 260 | 5.5 | 89.5 | 438 | 182 | 7,787 | 3,040 |
| 262 | 5.5 | 89.5 | 438 | 182 | 7,787 | 1,730 |
| 264 | 5.5 | 89.5 | 438 | 182 | 7,787 | 1,950 |
| 266 | 5.5 | 89.5 | 438 | 182 | 7,787 | 1,730 |
| 270 | 80 | 140 | 2,080 | 2,040 | 11,460 | 55,310 |
| Totals | | | 9,754 | 8,020 | 151,450 | 105,240 |

TABLE 33

Sensible Heat Load Breakdown

Third Floor, Building 3

Southwest Side

| Room No. | Shaded Glass $Ft^2$ | Exposed Glass $Ft^2$ | Wall Btuh | Shaded Glass Btuh | Exposed Glass Btuh | Internal Load Btuh |
|---|---|---|---|---|---|---|
| 331 | 4 | 52 | 663 | 108 | 5,668 | 1,420 |
| 333 | 6 | 96 | 366 | 162 | 10,464 | 8,680 |
| 335 | 6 | 96 | 366 | 162 | 10,464 | 8,680 |
| 339 | 6 | 96 | 346 | 162 | 10,464 | 11,090 |
| 339 (A) | 6 | 96 | 276 | 162 | 10,464 | 2,390 |
| 339 (B) | 6 | 96 | 300 | 162 | 10,464 | 1,735 |
| 339 (D) | - | - | - | - | - | 4,400 |
| 343 | 12 | 192 | 713 | 324 | 20,928 | 18,020 |
| 347 | 12 | 192 | 688 | 324 | 20,928 | 179,450 |
| 351 | 12 | 192 | 688 | 324 | 20,928 | 179,450 |
| 355 | 12 | 192 | 688 | 324 | 20,928 | 179,450 |
| 359 | - | - | - | - | - | 1,735 |
| 359 (A) | 6 | 96 | 436 | 162 | 10,464 | 1,735 |
| 359 (B) | 6 | 96 | 346 | 162 | 10,464 | 1,955 |
| 359 (C) | - | - | - | - | - | 2,390 |
| 363 | - | - | - | - | - | 30,000 |
| 365 | 6 | 96 | 346 | 162 | 10,464 | 89,460 |
| 365 (B) | 6 | 96 | 256 | 162 | 10,464 | 3,080 |
| 369 | - | - | - | - | - | 65,000 |
| 382 | 3 | 38 | 740 | 81 | 4,450 | 2,610 |
| Totals | | | 7,218 | 2,943 | 188,006 | 792,730 |

Northeast Side

| Room No. | Shaded Glass $Ft^2$ | Exposed Glass $Ft^2$ | Wall Btuh | Shaded Glass Btuh | Exposed Glass Btuh | Internal Load Btuh |
|---|---|---|---|---|---|---|
| 332 | 2 | 41 | 448 | 50 | 3,724 | 2,400 |
| 334 | 2 | 54 | 413 | 66 | 4,698 | 1,080 |
| 334 (A) | - | - | - | - | - | 1,080 |
| 336 | 2 | 54 | 434 | 66 | 4,698 | 1,730 |
| 338 | 2 | 54 | 434 | 66 | 4,698 | 1,730 |
| 340 | 2 | 54 | 434 | 66 | 4,698 | 1,730 |
| 342 | 2 | 54 | 434 | 66 | 4,698 | 1,080 |
| 342 (A) | - | - | - | - | - | 1,080 |
| 344 | 4 | 108 | 980 | 132 | 9,396 | 1,080 |
| 348 | 33 | 88 | 382 | 1,089 | 7,656 | 1,080 |
| 350 | 33 | 110 | 240 | 1,089 | 9,570 | 1,080 |

TABLE 33
(Continued)

| Room No. | Shaded Glass $Ft^2$ | Exposed Glass $Ft^2$ | Wall Btuh | Shaded Glass Btuh | Exposed Glass Btuh | Internal Load Btuh |
|---|---|---|---|---|---|---|
| 352 | 33 | 88 | 382 | 1,089 | 7,656 | 1,080 |
| 354 | 2 | 54 | 434 | 66 | 4,698 | 1,730 |
| 356 | 2 | 54 | 434 | 66 | 4,698 | 1,730 |
| 358 | 2 | 54 | 434 | 66 | 4,698 | 1,730 |
| 360 | 2 | 54 | 434 | 66 | 4,698 | 1,730 |
| 362 | 2 | 54 | 434 | 66 | 4,698 | 1,730 |
| 364 | 2 | 54 | 434 | 66 | 4,698 | 1,730 |
| 366 | 2 | 54 | 434 | 66 | 4,698 | 1,950 |
| 370 | 8 | 74 | 1,860 | 264 | 5,095 | 41,925 |
| Totals | | | 9,479 | 4,505 | 99,473 | 75,145 |

TABLE 34

Sensible Heat Load Breakdown

Fourth Floor, Building 3

Southwest Side

| Room No. | Shaded Glass $Ft^2$ | Exposed Glass $Ft^2$ | Wall and Roof Btuh | Shaded Glass Btuh | Exposed Glass Btuh | Internal Load Btuh |
|---|---|---|---|---|---|---|
| 431 | 4 | 48.5 | 1,835 | 108 | 5,300 | 1,420 |
| 433 | 4.7 | 55.3 | 1,435 | 128 | 6,030 | 3,650 |
| 435 | 4.7 | 55.3 | 1,278 | 128 | 6,030 | 3,360 |
| 437 | 4.7 | 55.3 | 1,702 | 128 | 6,030 | 3,360 |
| 439 | - | - | 504 | - | - | 1,410 |
| 439 (A) | 4.7 | 55.3 | 941 | 128 | 6,030 | 2,390 |
| 441 | 4.7 | 55.3 | 1,436 | 128 | 6,030 | 3,360 |
| 443 | 4.7 | 55.3 | 1,436 | 128 | 6,030 | 3,360 |
| 445 | - | - | 504 | - | - | 1,410 |
| 445 (A) | 4.7 | 55.3 | 941 | 128 | 6,030 | 2,390 |
| 447 | 4.7 | 55.3 | 1,436 | 128 | 6,030 | 3,360 |
| 449 | - | - | 504 | - | - | 1,410 |
| 449 (A) | 4.7 | 55.3 | 941 | 128 | 6,030 | 2,390 |
| 451 | - | - | 504 | - | - | 1,410 |
| 451 (A) | 4.7 | 55.3 | 941 | 128 | 6,030 | 1,410 |
| 453 | - | - | 504 | - | - | 1,410 |
| 453 (A) | 4.7 | 55.3 | 941 | 128 | 6,030 | 1,410 |
| 455 | - | - | 504 | - | - | 1,410 |
| 455 (A) | 4.7 | 55.3 | 941 | 128 | 6,030 | 1,410 |
| 457 | - | - | 504 | - | - | 1,410 |
| 457 (A) | 4.7 | 55.3 | 941 | 128 | 6,030 | 1,410 |
| 459 | - | - | 504 | - | - | 1,410 |
| 459 (A) | 4.7 | 55.3 | 941 | 128 | 6,030 | 1,410 |
| 461 | - | - | 504 | - | - | 1,410 |
| 461 (A) | 4.7 | 55.3 | 941 | 128 | 6,030 | 1,410 |
| 463 | 4.7 | 55.3 | 1,067 | 128 | 6,030 | 1,630 |
| 465 | 53 | 45 | 2,450 | 1,948 | 5,880 | 3,490 |
| 482 | 3 | 20 | 1,128 | 81 | 2,180 | 2,000 |
| 482 (A) | 9 | 64 | 2,397 | 243 | 6,976 | 3,360 |
| Totals | | | 30,605 | 4,428 | 116,816 | 60,670 |

Note: Roof = 21,049; wall = 9,556

TABLE 34
(Continued)

Northeast Side

| Room No. | Roof Btuh | Skylight Btuh | Wall Btuh | Internal Load Btuh |
|---|---|---|---|---|
| 432 | 363 | 7,980 | 702 | 1,940 |
| 434 | 1,300 | 13,020 | 1,180 | 101,300 |
| 438 | 1,300 | 13,020 | 1,180 | 101,300 |
| 442 | 650 | 6,500 | 586 | 11,200 |
| 444 | 650 | 6,500 | 586 | 11,200 |
| 446 | 1,300 | 13,020 | 1,180 | 22,400 |
| 450 | 650 | 6,500 | 586 | 12,140 |
| 452 | 1,300 | 13,020 | 1,180 | 14,840 |
| 456 | 1,300 | 13,020 | 1,180 | 14,840 |
| 462 | 1,300 | 13,020 | 1,180 | 14,840 |
| 464 | 1,300 | 13,020 | 1,180 | 14,840 |
| 470 | 4,092 | - | 5,300 | 16,200 |
| Totals | 15,505 | 118,620 | 16,020 | 337,040 |

TABLE 35

Sensible Heat Load Breakdown

Basement, Building 3

| Room No. | Shaded Glass $Ft^2$ | Exposed Glass $Ft^2$ | Wall Btuh | Shaded Glass Btuh | Exposed Glass Btuh | Internal Load Btuh |
|---|---|---|---|---|---|---|
| 050 | 34 | 444 | 14,324 | 920 | 48,500 | 536,950 |
| 037 | 3.8 | 52.2 | 342 | 103 | 5,700 | 1,400 |
| 055 | 3.8 | 52.2 | 342 | 103 | 5,700 | 18,321 |
| 057 | 3.8 | 52.2 | 342 | 103 | 5,700 | 20,050 |
| 059 (A) | 3.8 | 52.2 | 415 | 103 | 5,700 | 17,100 |
| 059 (B) | 3.8 | 52.2 | 770 | 103 | 5,700 | 21,132 |
| 059 (C) | 3.8 | 52.2 | 690 | 103 | 5,700 | 20,521 |
| 054 | - | - | - | - | - | 44,697 |
| 056 | - | - | - | - | - | 44,697 |
| 058 | - | - | - | - | - | 44,697 |
| 060 | - | - | - | - | - | 44,697 |
| 062 | - | - | - | - | - | 44,697 |
| 064 | - | - | - | - | - | 44,697 |
| 066 | - | - | - | - | - | 14,000 |
| 068 | - | - | - | - | - | 11,400 |
| 068 (A) | - | - | - | - | - | 11,120 |
| 070 | - | - | 895 | - | - | 12,590 |
| Behind Test Cells | - | - | 5,150 | - | - | 8,010 |
| Outside 068 | - | - | - | - | - | 3,280 |
| Front Test Cells | - | - | - | - | - | 4,100 |
| Inside Exterior Door | - | 24 | 350 | - | 2,620 | 1,207 |
| Totals | | | 23,620 | 1,538 | 85,320 | 963,363 |

## REFERENCES

A. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Handbook of Fundamentals, 1967.

B. Robert Snow Means Co., Inc., Building Construction Cost Data, 1968.